1991 CORNWALL LOW-LEVEL METALS SURVEY

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EXECUTIVE SUMMARY

In July 1991, water samples were collected from 12 stations in the St. Lawrence River in the Cornwall area, and analyzed at the Dorset laboratory for heavy metals at ultra-low detection limits. At the same time, samples were collected of the point source and tributary inputs to the river, water samples in the river for conventional pollutants, and suspended and bottom sediments for conventionals and metals. These samples were collected in support of a project to develop and calibrate a fate and transport model for heavy metals, a subject which will be the topic of a subsequent report.

For all metals but zinc, the Domtar/ICI/Cornwall Chemicals combined sewer is the largest single point source. For zinc, the Courtaulds acid sewer was the largest point source at the time of the survey; however, Courtaulds ceased operations in late 1992. Hence zinc loadings should be considerably reduced. Total point source loadings for zinc and chromium have decreased significantly in the past ten years. Some evidence also exists for decreased mercury loadings in recent years from the Cornwall STP. Trends for other metals could not be ascertained.

Within the study area, in-river water chemistry is largely controlled by the large throughput of water through the St. Lawrence River. However, many water quality parameters, both conventionals and low-level metals, exhibit higher levels in the north channel, which could be related to inputs from the Courtaulds and Domtar/ICI/Cornwall Chemicals discharges. Arsenic levels are slightly higher in the south channel, due to an input from Reynolds Metals, which was the only measurable input of this metal in the study area. Despite the higher levels in the north channel, all metal levels were below the relevant Provincial Water Quality Objectives.

Levels of metals and nutrients in suspended and bottom sediments are largely in exceedence of the Ministry's Sediment Quality Guidelines Lowest Effect level, with a few exceedences of the Severe Effect levels also found. Contaminant levels are higher in the fine-grained suspended sediments, than in the bottom sediments, which were found to be a mixture in varying proportions of coarse- and fine-grained materials. Evidence of the effect of the Domtar/ICI/Cornwall Chemicals and Courtaulds discharges was found from increased mercury and zinc levels in bottom sediments related to their grain size, and by zonation of the suspended sediment metals levels using the ratio matching/cluster analysis method. The effect of these sources is also noted in results of a hydrodynamic dispersion model of the study area.

Estimates of suspended metal levels were obtained as the product of metal concentrations in

suspended sediments and suspended sediment concentration. Observed particulate fractions ranged from about 2% for arsenic and nickel, to greater than 100% for iron. The latter result is likely an artifact of the fact that the suspended metal data, being collected from sediment traps, represents a time-integrated concentration, while the total metal levels in water represent one instant in time. Nevertheless, the particulate metal fractions should prove helpful in metals modelling.

1991 CORNWALL LOW-LEVEL METALS SURVEY

1.0 INTRODUCTION

The St. Lawrence River was initially identified by the International Joint Commission (IJC) as an Area of Concern because of PCB and Hg contamination in sediments and Provincial Water Quality Objective (PWQO) exceedences for phenols and coliform bacteria in the Cornwall-Massena area, as well as elevated mercury and organolead levels in fish at Maitland. In accordance with the IJC Water Quality Board recommendations, a Remedial Action Plan (RAP) is under development for this Area of Concern. The Stage I RAP (definition and description of the environmental problems and impaired beneficial uses) (RAP, 1991)has been completed and is under review by the IJC.

In general, the St. Lawrence River water quality reflects the input from Lake Ontario at Kingston, which is the source of 95 percent of the river water reaching Cornwall (RAP, 1991). However, inputs from industrial and municipal sources and tributaries in the Cornwall/Massena area have affected local water quality. The RAP document summarizes the environmental conditions and concerns in the Cornwall area, including bacteria, nutrients, inorganic and organic contaminants, drinking water, suspended and bottom sediments, biota, and aesthetics. Several exceedences of PWQOs for heavy metals are documented, including cadmium, copper, and zinc in 1979 and cadmium in 1988. Mercury was also mentioned as an element of concern, though 1988 results (Anderson and Biberhofer, 1990) were generally below the detection limit in water of 0.01 μg/L. High mercury and zinc levels originate from the Courtaulds and Domtar/ICI/Cornwall Chemicals discharges (see section below). Mercury and other metals may also have been mobilized from upstream sediments after inundation of Lake St. Lawrence during construction of the St. Lawrence Seaway in the 1950s.

In 1985, the Ontario Ministry of the Environment conducted an environmental study of the St. Lawrence River in the Cornwall area to evaluate the impact of local discharges on the area water quality, and to update the results of earlier (1979, 1980 and 1982) surveys (Anderson, 1990). Further surveys of the river water quality and source inputs were conducted as part of the St.

Lawrence River RAP investigations in 1988, 1989 and 1990 (Anderson and Biberhofer, 1990, 1991).

The 1985 report contained several findings and recommendations which are pertinent to the work carried out in 1991. These include the following:

1. 32% of water samples collected near the Courtaulds/BCL outfall exhibited zinc concentrations above the PWQO of 30 μg/L. Based on zinc concentrations in the effluent, it was concluded that Courtaulds/BCL is a significant zinc source, and it was recommended that zinc discharges be reduced to levels which would permit the river water to achieve PWQO.

2. Elevated concentrations of mercury, lead and zinc were found in sediments of the north river channel (adjacent to City of Cornwall). Spatial distribution of sediment data suggested that local sources, including Courtaulds/BCL and Domtar/ICI (formerly CIL) were contributing to this contamination. The ICI outfall is a known source of mercury. Further mercury loading reductions at ICI, as well as effluent control for these three metals at Courtaulds/BCL were recommended.

3. The spatial distribution of grain-size corrected sediment data for arsenic, cadmium, chromium, iron and nickel suggested that there are no significant local sources of these metals. However, maximum levels of most of these metals were observed near or downstream of the Courtaulds/BCL outfalls, with Provincial guidelines for dredged material disposal being exceeded for most of the metals. There is clearly a need for additional source identification.

Further sampling of water, suspended solids and effluents was conducted in support of the RAP in 1988-1990 (Anderson and Biberhofer, 1990, 1991). The objectives of these investigations included the determination of the relative significance of contaminant inputs from the Cornwall area compared to upstream; the identification of sources of contaminants in Cornwall discharges and the assessment of the need for further remedial measures; and the assessment of the impact of remedial measures already implemented.

Table 1 gives the average concentrations of major ions and trace metals observed in 1988-89. Major ions are included as these are essential inputs to the metals model. It is noted that the concentrations of most metals were low and relatively spatially uniform, as a result of the high dilution capacity of the river. Results for both years were very similar, except for zinc, which was slightly lower in 1989 compared to 1988. Data for the Raquette and St. Regis Rivers are included separately as these rivers exhibit unique chemistry reflective of their respective watersheds.

The objectives of the Cornwall low-level metals study are as follows:

1. To collect data for metals of concern, such as mercury, that will be useful in formulating remedial options for the Cornwall RAP.

2. To collect an input data set which will be useful in calibrating and validating the MINTEQA2 metal speciation model and its coupling with a fate and transport model such as EXAMS, which can be used to evaluate remedial options.

3. To continue the development and application of low-level metal techniques, begun at 1990 in Parry Sound, with field-filtration of metals and increased measurement of spatial resolution of metal concentrations. This is important because many metals occur at low concentrations, often below conventional detection limits, in many areas of the Great Lakes.

1.1 Cornwall/Massena Area Sources

The locations of the major industrial and municipal intakes and outfalls in the Cornwall-Massena area are shown in Figure 1 and Table 2. A brief description of each source, based on information found in the Stage I RAP (RAP, 1991) in the study area follows:

(a) Domtar Fine Papers, ICI Forest Products (formerly known as CIL; RAP, 1991) and Cornwall Chemicals discharge through a combined submerged diffuser which can be sampled through a manhole near the river (R. Helliar, MOE Cornwall district office). Domtar Fine Papers utilizes a bleached kraft process in which hardwood chips are converted into pulp by cooking under pressure with sodium hydroxide and sodium sulfide, followed by bleaching with chlorine, oxygen, sodium hydroxide and chlorine dioxide. ICI Forest Products produces sodium hydroxide and chlorine by electrolysis of salt solutions using the mercury cell process. Cornwall Chemicals produces several industrial chemicals from the chlorine and sodium hydroxide produced at ICI. As well as high concentrations of BOD and suspended solids, this effluent contains concentrations of mercury (ICI,CC), zinc (CC) and cadmium (Domtar,ICI) which exceed Ontario Industrial Effluent Objectives of 0.001, 1.0 and 0.001 mg/L, respectively (RAP,1991). Elevated levels of cadmium, chromium, copper, lead and zinc have also been observed at Domtar (RAP, 1991). Organic compounds such as resin and fatty acids, which may serve as metal complexing agents are also present.

TABLE 1

WATER QUALITY DATA, 1988-1989

	St. Lawrence R.				Raquette R.		St. Regis R.	
	1988		1989		1988		1988	
A. Trace metals (ug/L)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Arsenic	0.61	0.05	0.49	0.08	0.15	0.06	0.33	0.12
Barium	21.60	1.20	23.30	2.22	10.30	0.73	18.63	2.02
Chromium	0.62	0.26	0.54	0.69	0.48	0.10	0.43	0.06
Copper	0.94	0.24	1.24	0.41	0.32	0.10	0.43	0.38
Mercury	0.02	0.02	0.001	0.004	0.01	0.00	0.10	0.00
Lithium	1.92	0.22	2.51	0.54	0.35	0.19	1.03	0.46
Manganese	6.05	3.69	4.80	1.87	23.28	12.20	45.73	14.40
Molybdenum	0.97	0.10	0.98	0.14	0.05	0.17	0.40	0.35
Nickel	0.87	0.19	0.92	0.36	0.15	0.17	0.37	0.15
Selenium	0.21	0.21	0.13	0.08	0.47	0.68	0.03	0.12
Strontium	167.94	4.41	172.24	15.63	168.57	2.51	86.27	42.64
Vanadium	0.39	0.24	0.38	0.15	0.34	0.05	0.37	0.06
Zinc	8.75	7.91	5.49	2.21	9.96	9.23	16.23	10.39
B. Conventional parameters (mg/L)								
Ammonia-N	0.05	0.02	0.03	0.02	0.05	0.03	0.08	0.02
TKN	0.27	0.07	0.26	0.05	0.22	0.01	0.41	0.22
NO2+NO3 - N	0.17	0.07	0.18	0.09	0.14	0.03	0.13	0.04
Total P	0.02	0.01	0.02	0.00	0.02	0.02	0.03	0.01
silica	0.45	0.19	0.42	0.13	3.25	0.57	2.53	1.38
Alkalinity	78.70	4.88	92.85	4.49	15.88	2.87	49.80	21.10
Chloride	22.09	1.01	21.59	0.49	4.80	2.58	8.80	6.00
Sulfate	25.28	1.46	26.29	1.09	7.98	0.30	13.10	1.38
Calcium	36.30	1.77	37.01	0.94	6.80	0.73	18.73	8.73
Magnesium	8.03	0.26	7.89	0.37	1.95	0.31	4.77	1.48
Sodium	11.51	0.51	11.60	0.33	2.75	0.38	5.37	2.73
Potassium	1.42	0.05	1.45	0.03	0.56	0.08	0.88	0.25
Aluminum	0.09	0.10	0.07	0.03	0.08	0.01	0.10	0.02
Iron	0.10	0.12	0.07	0.03	0.28	0.06	0.33	0.13

TABLE 2

SAMPLING LOCATIONS, 1991 CORNWALL LOW-LEVEL METALS SURVEY

Note: All locations are BOW=12.

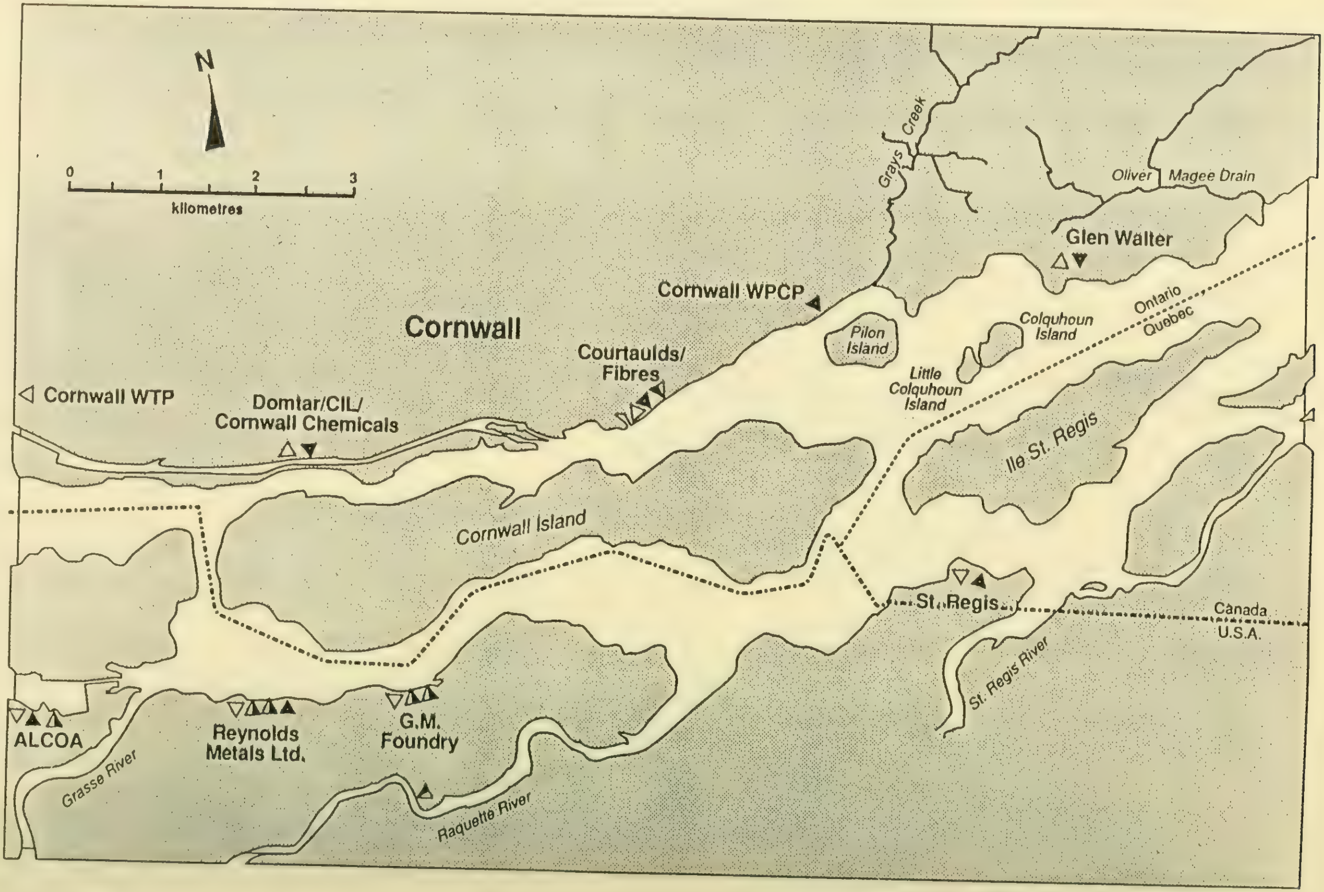
MOE Stn #	Latitude	Longitude	Description
(a) In-river stations (station type = 02)			
401	45-00-09	74-47-14	Upstream control, just below power dam
476	45-00-42	74-43-48	about 1 km downstream of Domtar/ICI
431	45-01-09	74-41-12	about 0.4 km downstream of Courtaulds/BCL
477	45-01-43	74-40-09	north of Pilon island, close to island
436	45-01-14	74-39-56	about 0.7 km downstream of Cornwall STP
437	45-00-49	74-39-42	channel between Cornwall and St. Regis is.
443	45-01-47	74-38-44	north of Colquhon islands
444	45-01-30	74-38-18	north of St. Regis island, S. edge of ship
478	44-59-24	74-43-42	downstream of GM, just E. of buoy,near shore
479	44-59-49	74-40-46	downstream of Raquette I,offshore from point
402	45-00-44	74-37-45	between St. Regis and Yellow islands
441	45-00-10	74-37-38	south of Yellow island
(b) Input Locations (station type = 03 [STP], 09 [industrial], and 21 [water intake])			
09-35	45-00-36	74-44-35	Domtar/ICI/Cornwall Chemicals
09-36	45-01-09	74-41-44	Courtaulds acid sewer
09-37	45-01-09	74-41-44	Courtaulds sulphide sewer (not flowing)
09-38	45-01-09	74-41-44	Courtaulds viscose sewer
09-39	45-01-09	74-41-45	Courtaulds combined storm sewer
09-40	45-01-12	74-41-38	Courtaulds tank car unloading sewer
09-44	45-01-06	74-41-52	Courtaulds acid recovery sewer
09-45	45-01-10	74-41-42	Caravelle Carpets sewer
09-41	44-59-10	74-45-10	Reynolds Metal Co. main surface sewer
09-42	44-59-10	74-44-10	Reynolds Metal Co. second sewer(submerged)
09-43	44-59-14	74-45-01	General Motors main surface discharge
03-09	45-01-45	74-40-47	Cornwall STP
21-01	45-00-41	74-45-28	Domtar/ICI raw water intake
(c) Tributary Mouths (station type = 15, except St. Regis)			
15-02	44-58-32	74-47-21	Grasse River (ref. pt. power line)
15-03	44-59-13	74-41-27	Raquette River (tip first isle)
02-381	45-00-00	74-38-27	St. Regis River (near mouth)

Figure 1

St. Lawrence Remedial Action Plan - Cornwall / Lake St. Francis area

Location of major industries, intakes and outfalls

(Anderson 1990)



△ Intake

▲ Outfall (in pipe)

Δ Outfall (in river at shore)

(b) Courtaulds Fibres (figure 2), produced rayon by treating wood pulp with sodium hydroxide and carbon disulfide to form an intermediate product called viscose. The viscose is injected into a sulfuric acid bath containing zinc and sodium sulfate to form the rayon fibres. They used to discharge waste through several sewers: (i) combined acid sewer, which discharged an acidic, high-Zn waste to an offshore submerged diffuser; (ii) viscose sewer, which discharged an alkaline, high-BOD waste; (iii) combined storm sewer, which historically has been contaminated with process wastewater and discharged at a shore-based outfall; (iv) tankcar unloading area sewer, which discharged at a second shore-based outfall; (v) acid recovery sewer, which is mainly cooling and condensate water; and (vi) Caravelle Carpets sewer, which also discharged mainly cooling and condensate water (its name was taken from the former Caravelle Carpets plant on this site which closed in 1981). Ontario Industrial Effluent Objectives are exceeded in at least one effluent stream for pH, suspended solids, mercury and zinc. Since the present investigation was conducted, Courtaulds Fibres discontinued operations. Hence, the above sewers are no longer discharging effluents. The site remains to be decommissioned.

(c) Cornwall WPCP, a primary sewage treatment plant which also receives several industrial wastes and discharges to an offshore diffuser.

(d) General Motors Central Foundry Division in New York State operates a factory that makes aluminum automobile parts. It discharges wastes at one surface sewer and one submerged sewer to the St. Lawrence River. New York State Department of Environmental Conservation (NYSDEC) monitors Cr, Cu, Fe and Al at these discharges.

(e) Reynolds Metal Co. in New York State operates an aluminum production plant which discharges waste at one surface sewer and one submerged sewer to the St. Lawrence River. NYSDEC monitors Zn and Al at the Reynolds discharge (B. Mead, NYSDEC, pers. comm.).

(f) ALCOA (Aluminum Corporation of America) operates a plant making aluminum and aluminum products that discharges to the Grasse River in Massena, upstream of the St. Lawrence. Because its input is contained in that of the Grasse River, this source was not monitored in this study.

1.2 Heavy Metals Fate and Transport Model

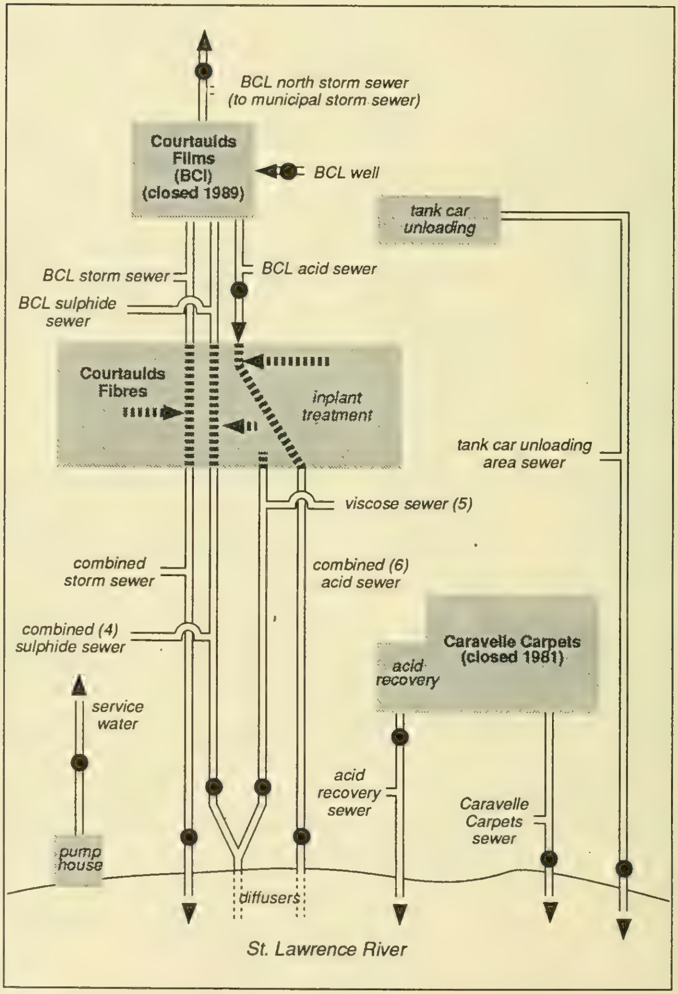
Up to present, many metals other than zinc and mercury have received less attention than organics despite the fact that many metals are significant toxicants in the aquatic system, and are hence included on priority pollutant lists such as the Ministry's Effluent Monitoring Priority

Figure 2

St. Lawrence Remedial Action Plan

Schematic of sewers at Courtaulds and Caravelle Carpets

(EPS 1985)



sampling points, 1985

Pollutants List (EMPPL). In addition, metal toxicity varies with the chemical form of the metal; for most metals the free (uncomplexed) metal ion is the most toxic; however, in some metals like mercury, organic forms (e.g. methylmercury) are the most toxic. Chemical speciation of metals is predicted by equilibrium models such as MINTEQA2. This is useful in several applications, some of which follow: In the laboratory, the toxic effect of metals and organics can be distinguished by adding a complexing agent; the model predicts the extent of complexation. For example, during toxicity studies, one may be able to more easily identify the toxicant responsible for the observed effects. For objectives development, toxicity-metal level relationships can be explored and objectives can be developed which take factors such as alkalinity and DOC into consideration. This may improve the accuracy and scientific defensibility of the proposed objective. Metal-nutrient interactions can be also explored; removal of phosphates can reduce the storage of excess phosphates in cell tissues which detoxify metals, and consequently can increase metal toxicity. These are important for assessment of remedial options in Areas of Concern or other contaminated areas.

The USEPA geochemical metals model MINTEQA2 is being interfaced with EXAMS, an organic contaminant fate and transport model. MINTEQA2 uses fundamental thermodynamic equilibrium relationships to calculate dissolved, adsorbed and precipitated metal concentrations. It handles reactions among gases, aqueous solutions, mineral phases, and adsorbed phase species, by the simultaneous solution of mass action (chemical equilibrium) and mass balance equations for the various chemical species present in the system. MINTEQA2 also includes temperature and ionic strength (activity) corrections, as well as formation of new solids (precipitation). Several formulations are also available for adsorption of trace metals onto solid phases. Additional details of MINTEQA2 are given elsewhere (Brown and Allison, 1987).

Input of contaminants and their transport are treated by EXAMS. This model handles point and nonpoint source loadings, atmospheric washout and groundwater seepage. Transport by advection, dispersion and volatilization are handled. When the two models are coupled, they operate iteratively as follows: EXAMS calculates an initial distribution of total metals based on source inputs and transport data; MINTEQA2 uses this to calculate the detailed metal speciation in each model compartment. The fractions of total metal in each chemical species are then used by EXAMS to calculate further transport results; this procedure can operate iteratively. The coupled model can be used to predict toxicity and its spatial variation; it can also assist in the development of remedial options and water quality-based effluent loading limits as appropriate.

The operation and product of the MINTEQA2/EXAMS model will be the subject of a separate report yet to be published.

1.3 Low-level metals sampling

In July 1990, a pilot project for low-level heavy metals in water was undertaken at Parry Sound by the Great Lakes Section, in cooperation with the Dorset Research Centre (MOE unpublished data). The purposes of this study included the establishment of the adequacy of on-board sampling techniques currently used by the Great Lakes Section for low-level metals, plus the adequacy of current MOE laboratory procedures for these tests.

The results of this survey showed that field methods were probably adequate for obtaining representative samples. Nearly all metals sought were detected with acceptably low standard deviations; only a few random data points showed evidence of contamination (which appeared to originate from the laboratory). Some recommendations regarding sampling method improvements were incorporated in the design of the current project. It was also found that additional refinement of laboratory methods would be helpful, including improvement of detection limits for chromium, copper and zinc.

2.0 STUDY OUTLINE AND METHODOLOGY

This project was planned with the use of the MINTEQA2 model in mind. This dictated certain data requirements, which are summarized as follows:

1. Concentrations of heavy metals to be modelled in water (total and filtered), suspended and bottom sediment and inputs to system. Filtered metals in receiving water are important as the model requires partitioning of metal between the two phases. The inputs include both tributaries and point source inputs.

2. Description of system hydrology. For the river, flow data at the Moses-Saunders power dam will be employed. These data will be proportioned across the various reaches of the system with the aid of acoustic doppler current profiler (ADCP data collected in 1990 by P. Nettleton (in prep.). This instrument measures cross-sectional profiles of current in various channels of the river. In addition, flow rates of the various point sources, as obtained from the industries and STP, will be employed.

3. General chemistry of water, suspended sediment and system inputs. This includes pH, redox (or its estimate from D.O.), major cations, major anions (for estimation of ionic strength and extent of complexation of various metals), and trace constituents (which may

form complexes).

These data were collected at 12 river stations, 3 tributary stations and 13 point source input locations (Table 2, Figure 3). During the survey period, all in-river stations were visited twice.

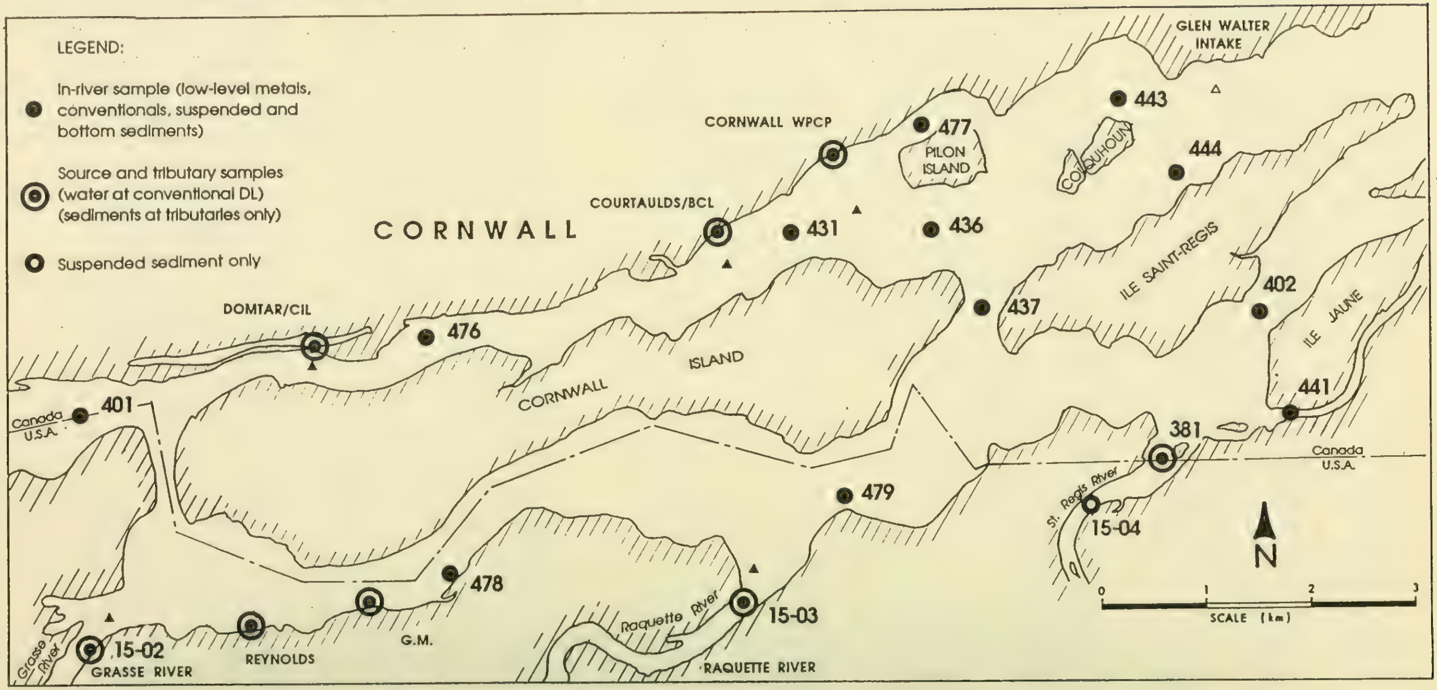
2.1 Low-level metal sampling

At each of the 12 river stations, four total metal replicates and four filtered metal replicates were collected per run, with two sampling runs being conducted during the two-week survey period in July 1991. Water samples were pumped from mid-depth at each station using a Masterflex peristaltic pump and specially-cleaned silicone tubing. The pump intake was deployed about 2m from the side of the vessel, using a bacti pole, in order to reduce the possibility of local contamination from the vessel itself. At each station, before sampling commenced, water was pumped to drain for at least five minutes, in order to clear residual water from the pumping line. Sample water was then pumped into large teflon bottles for analysis at Dorset for Cu, Pb, Zn, and Cd; and small acid-washed plastic bottles for analysis at Rexdale (Drinking Water Laboratory) for As, Cr, Fe, Mn, and Ni. All bottles were rinsed at least three times with the sample water before filling. During sampling, each bottle was kept as much as possible within its plastic bag, and preservative was not added to these samples. All samples were shipped to Dorset within 48 h of collection; Dorset personnel added preservative and submitted Rexdale drinking water laboratory samples. Dorset personnel also cleaned and prepared all bottles before field work commenced.

Field-filtered metal samples were also collected, using an apparatus similar to that designed for Great Lakes low-level metal work by Rossmann and Barres (1988; figure 4). This apparatus consisted of an approximately 9.5 cm diameter, 250 Ml capacity polypropylene Buchner funnel, with an acid-washed polycarbonate membrane filter. For vacuum filtration, the funnel was fitted with a pliable plastic wrap ("parafilm") to form a seal with a hole drilled in the top of a polycarbonate-polypropylene vacuum desiccator. An oilless vacuum pump was used to obtain vacuum, in order to avoid cadmium contamination from pump oil.

Prior to the survey, the filtration procedure was field-tested during a Lake Erie survey in May 1991 (station 370). Blank samples were collected from raw (unfiltered) water, as well as with each of the three filters under test (polycarbonate, polysulfone, and teflon). Samples were then collected of lake water as follows: Four unfiltered, six polycarbonate filtered, six polysulfone filtered, five teflon filtered, and three additional raw water samples. These consisted of both the high-density polyethylene bottles and small acid-washed disposable plastic bottles.

FIGURE 3: SAMPLING LOCATIONS
CORNWALL LOW-LEVEL METALS SURVEY, 1991



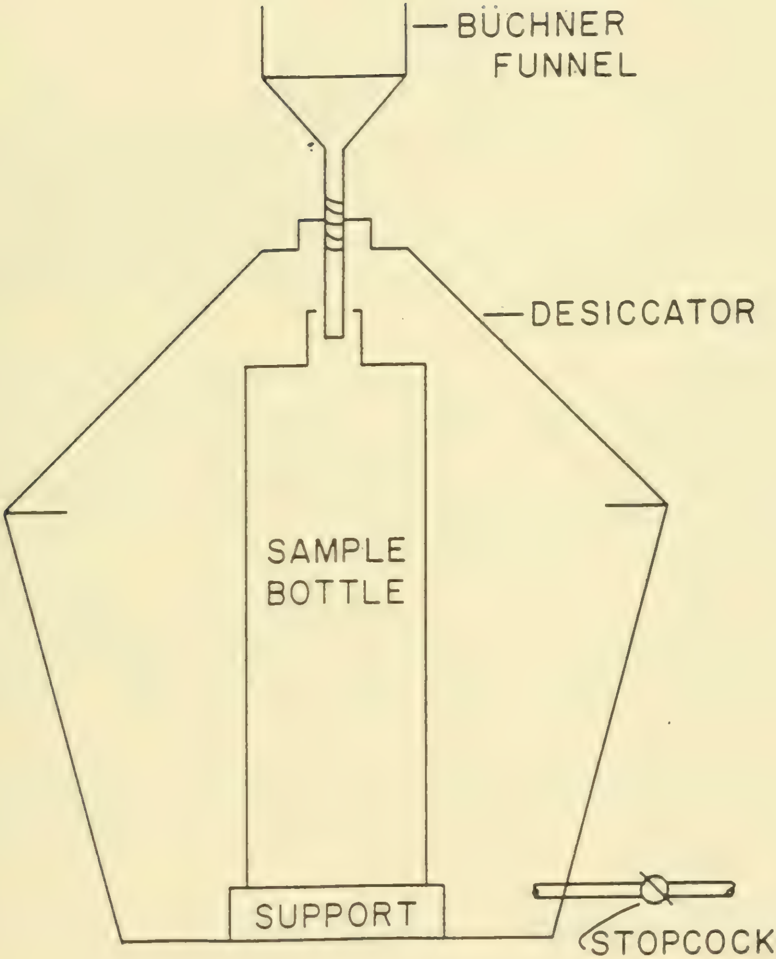


FIG. 4 Equipment used for the filtration of Great Lakes water samples.

Based on results for cadmium, lead and copper (table 3), polycarbonate was selected as the filter to be used. This filter medium gave the lowest relative standard deviations of all three filters; while the concentrations obtained by this filter were higher than those obtained for polysulfone, they were similar to those obtained with teflon for Pb and Cu, and approximately equal to or lower than the raw water samples (except for the ending raw samples with Cu, which had a large standard deviation and seem questionable). Besides being somewhat erratic for Cd and Pb, the teflon filters suffered from an excessive filtration time (1/2 hour per sample). Polysulfone was erratic in the case of cadmium. Zinc data (not presented here) were erratic for all filter media, and also for raw water; B. LaZerte (Dorset; pers. comm.) states that this metal is more subject to contamination problems than the other metals, and the analytical method used in the field test samples from Lake Erie (hanging mercury drop ASV, no digestion) was not as sensitive as the graphite furnace atomic absorption spectroscopy (GFAAS) method used in analyzing the St. Lawrence survey samples.

Blank samples were collected daily as follows. For total metals, three of each type of sample bottles were rinsed three times and filled with distilled-deionized water prepared at Dorset. These were left exposed to the air for the period of sampling at one station, capped and submitted as per usual. For filtered metals, distilled-deionized water was filtered and collected in sample bottles for one samples after each station. Except for pumping, the sampling procedure was identical to that described above.

Cadmium, copper, lead and zinc were analyzed at the Dorset Research Centre. These metals were analyzed by GFAAS with automated sample injection. Further details on the Dorset analytical methods are given in Lazerte et al (1989) and Mierle (1990).

The other metals were analyzed by inductively coupled argon plasma (ICP)-mass spectrometry at the Rexdale lab, drinking water station, without preconcentration. At present, facilities for these metals are not available at Dorset, and the drinking water station provides the best available detection limit.

Due to lack of laboratory resources, mercury sampling in the receiving water was not performed in this survey.

2.2 Conventional receiving water sampling

At the same time the low level metal samples were collected, replicate conventional water samples were collected from the same water depth at each of the same stations sampled for low level metals. These samples were analyzed at Rexdale for general chemistry, nutrients and

TABLE 3

PRELIMINARY FILTERED METAL RESULTS, LAKE ERIE, MAY 1991 (μg/L)

Sample		Cd	Pb	Cu
Raw blanks		0	0.011	0
		0	0.009	0
Polycarbonate blank		0	0.003	0
Polysulfone blank		0	0.003	0
Teflon blank		0	0.007	0
Starting raw samples	mean	0.031	0.467	1.72
	sd	0.005	0.256	0.37
Polycarbonate samples	mean	0.024	0.366	1.76
	sd	0.002	0.035	0.23
Polysulfone samples	mean	0.039	0.092	1.43
	sd	0.063	0.046	0.37
Teflon samples	mean	0.052	0.356	1.69
	sd	0.020	0.083	0.16
Ending raw samples	mean	0.028	0.352	0.69
	sd	0.006	0.076	0.40

major ions. In addition, a profile of temperature, conductivity and dissolved oxygen was taken at 1 m depth intervals. Samples collected at each of the tributary mouth locations included the same series of conventional samples plus a sample for heavy metals analysis at conventional detection levels at Rexdale.

2.3 Source Sampling

During the survey cruise period, replicate samples of effluent were collected from each of the point sources (STP and industrial discharges) in the Cornwall-Massena area (table 2), plus the Domtar intake and the GM discharge at Massena. Sampling at Reynolds Metals in Massena was performed by the New York State Department of Environmental Conservation. For modelling purposes, flow data were also obtained from the industries with the assistance of R. Helliar (MOE Cornwall district office).

2.4 Suspended Sediment Sampling

Suspended sediments were collected using sediment traps installed at all 12 river and 3 tributary mouth stations. These were deployed between July 8 and 10, 1991, and removed between July 29 and 30, 1991 in the same order as that in which they were deployed. At each station, duplicate assemblies of three tubes each were attached to each of two fence posts which had been inserted vertically into the river bottom. Each sediment-trap assembly was constructed with three ABS plastic tubes, each of which had an inside diameter of 10 cm and a length of 60 cm. The openings of the sediment-trap tubes were positioned 1 meter above the substrate. All deployment and retrieval activities were performed by Tarandus Associates Limited under contract to the Ministry. Further details of the sediment trap project are available in Tarandus, 1991.

2.5 Bottom Sediment Sampling

Surficial sediment grabs were collected in replicate at each of the 15 in-river and tributary stations during the July survey. All samples were analyzed for particle size (one of each replicate only), general chemistry and heavy metals.

3.0 RESULTS AND DISCUSSION

Results of the 1991 survey are presented and discussed with respect to inputs to the St. Lawrence River, followed by water, suspended and bottom sediments. References to conventional water quality parameters are included as they serve to define both the transport pattern of metals, as well as their chemical speciation in the combined metals transport model.

3.1 Source sampling

As mentioned in section 1.1, the Cornwall-Massena area is affected by numerous municipal and industrial inputs. Domtar and ICI discharge to the river at a combined submerged sewer. Courtaulds discharges at six separate sewers. City of Cornwall sewage is discharged by the Cornwall WPCP. On the U.S. side, two discharges from Reynolds Metals and one discharge from General Motors are found. In addition, three major tributary streams discharge to the St. Lawrence River on the U.S. side; the discharge from the Grasse River includes upstream inputs from Alcoa Ltd. and the Massena STP, not monitored separately in this study.

In this section, the emphasis is on the loading of heavy metals to the River from various sources, as required for input to the heavy metals transport model. Average heavy metal loadings are summarized in Tables 4 and 5 for the two survey weeks, respectively. They have been separated because the second week concentrations and loadings are significantly higher than the first week for many of the metals. Detailed statistics of loadings for conventionals and metals are found in Appendix A.

Arsenic was below detection at all sources but Reynolds surface sewer (average loading 17 g/d). Cadmium was below detection at all locations but the Cornwall STP during the first survey week, but was found at several locations in the second week. The greatest loading of Cd (229 g/d) originated from the Domtar/ICI/Cornwall Chemicals outfall. This represented 69% of the total point source input of 330 g/d in the second week.

For all metals but zinc, the Domtar/ICI/Cornwall Chemicals combined sewer is the largest single point source in the Cornwall-Massena area. The Courtaulds acid sewer is the largest point source of zinc, accounting for approximately 80 percent of the point source inputs. Although many of the tributary concentrations were below detection, loadings could be significant if the flows were large; therefore maximum loadings were calculated as the product of detection limit times flow, and are given in Tables 4-5. The maximum loadings for mercury, nickel, and lead are high indicating possible significant loadings of these metals.

TABLE 4
CONTAMINANT LOADING TO ST. LAWRENCE RIVER (g/d)
CORNWALL LOW-LEVEL METALS SURVEY
JULY 17-19, 1991.

	Cr	Cu	Fe (kg/d)	Hg	Mn	Ni	Pb	Zn (kg/d)
Domtar/ICI/Cornwall Chemicals	1360	5170	82	32.2	24300	1140	2300	4.4
Courtaulds acid sewer	198	108	7.5	3.0	1640	220	400	191.
Courtaulds viscose sewer	24	28	0.60	2.12	43	18	106	2.75
Courtaulds combined storm sewer	217	131	3.55	<0.5	146	56	<70	4.1
Courtaulds tank car unloading sewer	200	144	18.8	<0.1	143	391	68	3.8
Courtaulds acid recovery sewer	277	191	6.93	<0.5	242	211	237	18.3
Caravelle Carpets sewer	72	38	0.98	<0.1	61	26	67	4.3
Reynolds Metal surface sewer	25	82	0.27	<0.04	12	33	15	0.621
Reynolds Metal submerged sewer	137	300	1.47	<0.2	540	51	<50	4.02
GM main surface discharge	10	17	0.28	<0.01	40	19	<4	0.023
Total all industries	**2520**	**6210**	**122**	**37.3**	**27200**	**2470**	**3200**	**233**
Cornwall STP	**356**	**236**	**7.3**	**<0.8**	**2330**	**277**	**653**	**0.613**
Grasse River	<300	700	125	<14	27500	2100	<3000	0.695
Raquette River	<1300	1980	396	<50	55500	<5000	<13000	2.600
St. Regis River	<300	510	153	-	15600	<1300	<3000	0.680
Total major tribs.	**<1900**	**3190**	**674**	**<64**	**98600**	**<8400**	**<19000**	**3.975**
GRAND TOTAL (not including "<")	**2880**	**9640**	**803**	**37.3**	**128000**	**2750**	**3900**	**238**

NOTE: "<" values were calculated as product of detection limit times flow, for data where metal levels were below detection limit ("<W").

TABLE 5
CONTAMINANT LOADING TO ST. LAWRENCE RIVER (g/d)
CORNWALL LOW-LEVEL METALS SURVEY
JULY 22-24, 1991.

	Cr	Cu	Fe (kg/d)	Hg	Mn	Ni	Pb	Zn (kg/d)
Domtar/ICI/Cornwall Chemicals	2510	9260	132	11.6	38100	2900	3500	6.9
Courtaulds acid sewer	17	178	12	4.3	1550	187	720	175
Courtaulds viscose sewer	207	7	0.20	1.11	19	11	47	0.54
Courtaulds combined storm sewer	304	70	5.37	0.8	203	131	107	11.3
Courtaulds tank car unloading sewer	86	190	6.37	<0.1	136	47	67	3.4
Courtaulds acid recovery sewer	652	82	4.22	<0.5	234	168	224	15.2
Caravelle Carpets sewer	91	31	1.05	<0.1	77	42	86	5.7
Reynolds Metal surface sewer	22	30	0.16	<0.04	8	36	26	0.345
Reynolds Metal submerged sewer	122	117	4.22	<0.2	1080	41	158	3.21
GM main surface discharge	17	5	0.06	<0.02	56	34	19	0.024
Total all industries	**4030**	**9970**	**166**	**17.8**	**41500**	**3600**	**4950**	**222**
Cornwall STP	**620**	**225**	**8.7**	**0**	**2450**	**451**	**653**	**1.08**
Grasse River	<300	700	167	<14	24000	<1400	<3000	1.04
Raquette River	<1400	2800	915	<50	81600	8400	<14000	4.20
St. Regis River	<300	580	136	-	17100	<1100	<3000	<0.3
Total major tribs.	**<2000**	**4100**	**1218**	**<64**	**122700**	**<10900**	**<20000**	**5.5**
GRAND TOTAL (not including "<")	**4650**	**14300**	**1393**	**17.8**	**166600**	**12500**	**5600**	**229**

NOTE: "<" values were calculated as product of detection limit times flow, for data where metal levels were below detection limit ("<W").

Metal loadings observed in 1991 may be compared to previous data to ascertain trends. Summary data (RAP,1990) for 1980-81 shows that total point source loadings for zinc and chromium have decreased significantly in the past ten years. Nickel and lead loadings have increased slightly in 1991, while copper and iron loadings were about the same.

More recent comparisons are possible using MISA monitoring regulation data, which span a 12-month period in 1989-90 for the industrial dischargers (MOE, 1992a,b,c). Relevant data are summarized in Appendix B. For the Domtar/ ICI/Cornwall Chemicals sewer, high MISA regulation monitoring detection limits (RMDL) and a large number of non-detects preclude comparisons for all metals except copper and zinc. Zinc loadings at 6 kg/d are similar, and copper at 1.7 kg/d is lower than that found here. However, copper concentrations varied by up to an order of magnitude from one day to the next during this survey, suggesting that the amount of data collected here is insufficient to comment on any loading trends. A partial comparison is possible for mercury, where the monitoring regulation data showed loadings of 63 g/d at ICI plus 2 g/d at Cornwall Chemicals. The total of 65 g/d is higher than the values of 32 and 12 g/d (Tables 4 and 5), suggesting a trend towards reduced mercury loadings.

At Cornwall STP, observed loadings are similar to those given in the 37-plant MISA survey done in 1987 (MOE, 1988) for most metals except zinc and mercury. In the case of zinc, present loadings are about one-half those of 1987. Mercury analyses done in the present survey were below the detection limit; a maximum loading calculated from the detection limit is about 40 percent of the 1987 figure.

At Courtaulds, loadings for copper, lead, zinc, and mercury are lower than those reported by MISA for the various outfalls; those for chromium and nickel are similar. However, available data are insufficient to place a level of significance on these observations; considerable variability (see Appendix A) was found in many cases.

In summary, the available data indicate a continuing decrease in zinc loadings over the past ten years, particularly at Domtar and the Cornwall STP. Some evidence exists for decreased loadings of chromium from Domtar and mercury from the Cornwall STP, and possible decreases in several metals from Courtaulds. Otherwise, data are of insufficient quality to confirm loading trends. No comparisons were possible for iron or manganese due to lack of other data.

3.2 River Water Quality Data

In this section, receiving water quality in the River is discussed. Tributary mouths, already discussed in Section 3.1, are mentioned where appropriate. Conventional parameters are used, both to define the spatial variation of river water quality, and to define transport and speciation properties for the heavy metals transport model.

3.2.1 QA/QC of Low-Level Metals Data

As described in section 2.3, extensive blank samples were taken during the low-level metals sampling, in order to check the extent of sample contamination. Table 6 gives concentrations of metals found in blanks. Detectable levels were found in at least a fraction of samples for nearly all metals. This was especially true for metals determined at Dorset (Cd, Cu, Pb, Zn). In fact, for Cd (both sample weeks), Cu and Zn (week 2), the median blank concentrations are higher than those actually observed in the field. This suggests that the blank water was inadequately purified prior to its being taken in the field, or that it was affected by a contamination source specific to the blanks only. For week 1, copper and lead blanks were a few percent of levels found in the river, a reasonable result. However, zinc blanks were highly variable and at times close in value to levels in the river. This suggests intermittent sporadic contamination with this metal. B. LaZerte (pers. comm.) has stated that contamination with zinc is often a problem in low-level metals collection; the results suggest that this did occur here, and results for this metal must, therefore, be interpreted with caution.

In week 2, blanks for copper, lead, and zinc were much higher than week 1 and highly variable; as mentioned above, copper and zinc blanks were higher than field results. It appears that further contamination of the "blank" water occurred at some unknown time, and/or an unknown source of field contamination was present during the second week. Why this contamination occurred only with the metals analyzed at Dorset is unknown. Nevertheless, the overall week 2 blank results suggest that field data for this week be used only with caution.

For metals determined at the Rexdale drinking water laboratory, blank results were reasonable in all cases, indicating only minor occasional contamination at levels below those found in ambient water.

For future work, it is suggested that metal analyses of the blank water should be done in advance of starting field work, so that its quality is ensured and contamination problems are rectified. As well, an additional series of blanks taken without exposure to ambient air or sampling lines would indicate if there was any contamination specific to the sampling system.

TABLE 6

CONCENTRATIONS OF METALS IN BLANK SAMPLES ($\mu g/L$)

Metal	Week 1				Week 2			
	Min.	Med.	Max.	% > DL	Min.	Med.	Max.	% > DL
(a) Total								
As	ND	ND	ND	0	ND	ND	.11	22
Cd	.023	.055	.110	100	.025	.033	.037	100
Cu	.021	.033	.134	100	1.83	2.92	4.83	100
Fe	ND	ND	6.5	33	ND	ND	5.6	33
Mn	ND	ND	.10	33	ND	.10	.10	78
Ni	ND	ND	.020	33	ND	ND	.20	11
Pb	.001	.003	.027	78	.001	.091	.319	100
Zn	.047	.171	.390	100	2.25	3.19	4.53	100
(b) Filtered								
As	ND	ND	ND	0	ND	ND	ND	0
Cd	.039	.051	.068	100	.032	.055	.086	100
Cu	.037	.061	.388	100	2.71	2.92	3.82	100
Fe	ND	4.9	7.9	92	1.9	3.3	6.8	100
Mn	.10	.10	1.30	100	.10	.10	.20	100
Ni	ND	.007	.030	50	ND	ND	.02	20
Pb	ND	.009	.027	92	.174	.401	.554	100
Zn	135	.60	1.56	100	1.51	3.03	9.18	100

Note: Min = minimum
Med = median
Max = maximum
DL = detection limit
ND = not detected

3.2.2 Filtered Low-Level Metals

Samples (4 replicates per station per visit) were filtered through polycarbonate filters housed in a vacuum desiccator (figure 4). Despite good results obtained during the May checkout, filtered metal levels were highly erratic during the survey. Table 7 gives average percentages of filtered metals relative to total, and their ranges with stations and survey weeks. For Cd, Pb, and Zn, filtered metal levels were greater than total by factors of 1.7, 1.8, and 2.7, respectively; for Zn, the maximum filtered result was 17 times higher than total at station 479 during the first survey week. In addition, standard deviations of the concentrations of filtered Cd, Pb, and Zn were considerably higher than for total. An analysis of variance model was used to partition total variance for each metal between stations, sampling weeks and filtered vs. total, plus station-week interaction (M. Walsh, pers. comm.). This showed significant differences between total and filtered metals ($P<0.01$) for all metals but As and Cu. Only Fe, Mn, and Ni showed significantly lower filtered levels; however, their proportions must be considered doubtful because of the overall results.

Possible sources of sample contamination during filtration that were observed include the following:

1. Bottles removed from plastic wrappers.
2. Handling of bottles during rinsing, they were in and out of the desiccator three times each.
3. Pumped water was exposed to boat air for several seconds, sitting in the filter funnel as it was drawn in. Thus there was a chance of dust etc. entering, as well as someone breathing on it.
4. Repeated opening and closing of plastic ziplock bag containing fresh filters.
5. Bottom end of filter funnel coming in contact with sample or inside rim of sample bottle.
6. Inside of filter funnel had a brown residue by end of day.
7. End of supply line from Masterflex pump.

Horowitz et al. (1992) also found significant effects of variables such as filter type or diameter, filtration method (pressure or vacuum), suspended solids levels in raw water, volume of water filtered, and pre-treatment of samples (e.g. by centrifugation or prefiltering through glass beads) on Fe and Al levels in water. Their results also implied that similar differences could be observed with other metals that are associated with Fe or Al hydroxides, clay particles, etc. They concluded that even with the use of tightly controlled sampling and sample processing procedures, potential artifacts due to environmental conditions such as suspended sediment or organic matter levels could still impact on observed dissolved metal concentrations. At low detection limits, such filtration artifacts could be even more important.

TABLE 7

RELATIVE LEVELS OF FILTERED METALS

1991 CORNWALL LOW-LEVEL METALS SURVEY

Metal	Average Percent (filtered/total) x 100	Range among stations
Arsenic	98	66 - 116
Cadmium	166	87 - 254
Copper	97	76 - 112
Iron	75	42 - 102
Manganese	78	51 - 110
Nickel	91	81 - 143
Lead	180	61 - 340
Zinc	267	57 -1700

For future work, improvements in equipment must be made if field filtration is to be employed. A solution is to use a laminar flow-through fume hood on board the sampling vessel, including an airlock for the sampling line coming from outside. This would reduce the extent of contact of external air and dust with the sample. The best, but most expensive, solution would be a clean room on board ship similar to that used by Rossmann and Barres (1988).

Alternately, samples can be filtered at a later time, using clean room facilities such as those existing at the Dorset laboratory. B. LaZerte (pers. comm.) noted that these facilities are available on advance notice. However, precipitation of metals can occur in transit due to changes in temperature, pH, CO_2 levels, etc. so that the proportion of filtered metal may not represent that of the sample in-situ. Nevertheless, this may represent the best practical solution to measuring filtered metal levels in the future.

Due to these filtration problems, no further use of the filtered metal data was employed.

3.2.3 River Water Quality Data

Due to the time required for collection of low-level metals samples, three days were required for completion of the survey grid each time. Therefore, data collected are not synoptic, and it is inappropriate to discuss temporal variation from a statistical point of view. A summary of low-level metals results obtained is given by station and survey week in Appendix C.

In-river and tributary water quality data were analyzed for water quality zones using a statistical procedure previously applied in the Toronto Waterfront (Poulton and Griffiths, 1986; Poulton and Beak, 1992), and in the Bay of Quinte (Poulton, 1992). In brief, the analysis of variance model first developed by El-Shaarawi and Kwiatkowski (1977) was used to separate normalized data for each chemical parameter into additive components representing spatial and temporal effects. Data were normalized using the Box and Cox series of transformations (Box and Cox, 1964), as follows:

$$\begin{aligned} Z_{ij} &= (Y_{ij}^{\lambda} - 1)/\lambda \quad (\lambda \neq 0) \\ &= \ln Y_{ij} \qquad (\lambda = 0) \end{aligned}$$

where Y_{ij} = concentration of parameter i at station j, Z_{ij} = normalized concentration, and λ = transformation parameter. The spatial effects for a series of parameters were further analyzed by principal components analysis, which converts correlated chemical data into a smaller number

of uncorrelated variables (principal components). Factor scores computed from these components for each station were then classified into groups representing stations with similar water quality, using cluster analysis. Further details of the methodology are given in the references noted above.

The results indicate that all in-river (St. Lawrence) stations belong to one cluster; stations 15-03 (Raquette River) and 381 (St. Regis River) form a cluster, while station 15-02 (Grasse River) is alone in its own cluster. All three tributary stations are characterized by low levels of most major ions; the Grasse River is distinguished by high nutrient levels which may originate from the Massena STP. General statistics of conventional and metal levels are given in Tables 8 and 9.

Concentrations of most conventional parameters in the St. Lawrence River are similar to those found in recent years by Environment Canada (Table 1). Levels of conventionals in the Raquette and St. Regis Rivers are qualitatively within the range of 1988 values observed. Alkalinity values measured during this survey in the various water bodies are higher than Environment Canada 1988 results, but similar to their 1989 results in the St. Lawrence River. Levels of ammonia and total phosphorus are, if anything, lower in 1991 than in 1988-89.

Within the river proper, spatial variation in water quality parameters was further elucidated by one-way analysis of variance following appropriate normalizing transformations (as done with the El-Shaarawi model above). The results are given in Table 10.

The fact that water quality is controlled to a large extent by upstream river flow is shown in the large number of conventional parameters for which spatial variation is not significant. On the other hand, significant ($\alpha < 0.05$) variations are found for suspended solids, conductivity, Na, K, Mg, Cl, SO4, and alkalinity. All the heavy metals analyzed at low levels, except chromium (which was frequently below its detection limit of 0.5 μg/L), showed significant spatial variation at $\alpha < 0.01$.

Interparameter relationships may also be analyzed using correlation coefficients. These were computed using the same transformations used above. Correlation coefficients between selected conventional parameters are given in Table 11 and between low-level metals in Table 12. These relationships were further examined using factor analysis.

TABLE 8

CONCENTRATIONS OF WATER QUALITY PARAMETERS, 1991 (mg/L unless otherwise indicated)

	St. Lawrence R*		Grasse R.		Raquette R.		St. Regis R.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ammonia-N	0.023	0.005	0.081	0.018	0.019	0.005	0.025	0.008
Total Kjeldahl N	0.26	0.11	0.51	0.14	0.26	0.01	0.45	0.15
(Nitrite+nitrate)-N	0.165	0.011	0.115	0.014	0.182	0.028	0.048	0.003
Total P	0.013	0.007	0.063	0.01	0.011	0.001	0.032	0.003
Susp. solids	3.15	0.72	2.90	0.18	3.07	1.08	2.83	0.78
Turbidity (FTU)	1.71	0.76	1.85	0.13	1.65	0.20	1.66	0.35
Diss. Organic C	2.28	0.20	3.85	0.30	3.57	0.29	4.03	0.21
Cond. (25C) (umho/cm)	303	6	231	8	101	29	170	17
Diss. Oxygen	8.54	0.54	8.42	1.49	7.69	0.78	7.77	0.86
Sodium	11.93	0.39	9.29	0.63	3.68	1.03	6.19	0.78
Potassium	1.45	0.06	1.25	0.08	0.63	0.09	0.93	0.06
Calcium	38.2	1.7	18.2	2.0	10.7	3.9	21.9	1.2
Magnesium	8.48	0.21	6.9	0.27	2.74	0.58	5.48	0.45
Strontium	0.153	0.005	0.115	0.006	0.058	0.034	0.078	0.012
Barium	0.019	0.001	0.017	0.001	0.013	0.002	0.016	0.001
Aluminum	0.042	0.075	0.040	0.008	0.063	0.015	0.068	0.035
Fluoride	0.118	0.007	0.36	0	0.07	0.011	0.08	0
Chloride	22.2	0.4	15.4	1.0	5.6	2.1	9.8	1.5
Sulfate	26.8	0.9	19.7	0.6	10.0	3.0	12.8	1.3
Alkalinity (CaCO3)	94.1	1.9	72.9	1.8	27.0	8.7	57.7	5.1

Note * Mean of stations in St. Lawrence River sampled in this survey.

TABLE 9

CONCENTRATIONS OF LOW-LEVEL HEAVY METALS, 1991 (µg/L)

	St. Lawrence R Week 1		St. Lawrence R Week 2		Grasse R.		Raquette R.		St. Regis R.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Arsenic	0.759	0.105	0.831	0.165	ND	-	ND	-	ND	-
Cadmium	0.026	0.005	0.023	0.005	ND	-	ND	-	ND	-
Copper	0.886	0.086	0.956	0.166	1	0	0.9	0.3	0.75	0.35
Iron	39.7	6.4	43.8	5.9	210	36	238	102	230	8
Manganese	5.5	0.9	5.9	0.8	37	3	25	5	26	4
Nickel	4.16	0.59	4.65	0.13	ND	-	ND	-	ND	-
Lead	0.136	0.016	0.184	0.065	ND	-	ND	-	ND	-
Zinc	0.72	1.09	2.84	1.97	1.3	0.5	1.3	0.5	0.75	0.29

NOTE: Week 1 refers to period of July 17-19, 1991.
Week 2 refers to period of July 22-24, 1991.

Only metals at the St. Lawrence R. were done by the low-level methods described in text. Metals at other locations were done at Rexdale using conventional detection limits.

TABLE 10

ONE-WAY ANALYSIS OF VARIANCE

ST. LAWRENCE RIVER DATA AT CORNWALL, 1991

Parameter	Transf. Parameter λ	F value	Significance level
(a) Conventionals			
NH_3-N	1.0	0.85	NS
TKN	1.0	2.38	S
(NO_2+NO_3)-N	0.0	0.38	NS
Total P	0.5	2.62	S
Susp. Solids	0.0	7.02	S
Turbidity	0.5	2.06	NS
Diss. Org. C	-3.0	2.58	S
Conductivity (25C)	10.0	16.49	S
Sodium	3.0	15.44	S
Potassium	-3.0	7.70	S
Calcium	-4.0	1.05	NS
Magnesium	5.0	5.80	S
Strontium	--	0.68	NS
Barium	--	1.58	NS
Aluminum	-0.5	1.88	NS
Fluoride	--	1.64	NS
Chloride	10.0	5.48	S
Sulfate	4.0	5.65	S
Alkalinity	10.0	10.28	S
(b) Low-level metals			
Arsenic	1.0	3.01	S
Cadmium	1.0	7.31	S
Copper	1.0	5.10	S
Iron	1.0	2.83	S
Manganese	-1.5	9.34	S
Nickel	3.0	3.87	S
Lead	-2.0	2.71	S
Zinc	0.5	6.51	S

Note: Degrees of freedom for most conventionals = 11,36
Degrees of freedom for most metals = 11,86
S,NS = significant or not significant, $\alpha = 0.05$

TABLE 11

INTERPARAMETER CORRELATIONS
involving conventional water quality parameters

1991 Cornwall low-level metals survey

Correlations:	COND25	NNTKUR	NNOTFR	RSP	TURB	DOC	NAUR	KKUR	CAUR	MGUR	CLIDUR	SSO4UR	ALKT
COND25	1.0000	-.1053	.2708	.5758**	.3574*	.3115	.7885**	.5357**	.2637	.7035**	.8304**	.8587**	.9584**
NNTKUR	-.1053	1.0000	.1723	-.2570	-.1895	.0514	-.2328	-.2338	.4295*	-.0844	-.1133	-.0504	-.0362
NNOTFR	.2708	.1723	1.0000	.3851*	.3891*	-.1385	-.1412	.0214	.5636**	-.0217	.0706	.2010	.4361
RSP	.5758**	-.2570	.3851*	1.0000	.7224**	.2771	.4504**	.2071	.0904	.2174	.4601**	.3913*	.5785**
TURB	.3574*	-.1895	.3891*	.7224**	1.0000	.2504	.2374	.1596	-.0131	.0005	.2980	.2084	.3703*
DOC	.3115	.0514	-.1385	.2771	.2504	1.0000	.2884	-.0084	.1250	.3828*	.2564	.2980	.2527
NAUR	.7885**	-.2328	-.1412	.4504**	.2374	.2884	1.0000	.5444**	-.0535	.6000**	.7724**	.6814**	.6578**
KKUR	.5357**	-.2338	.0214	.2071	.1596	-.0084	.5444**	1.0000	-.2184	.5208**	.5423**	.4414**	.4941**
CAUR	.2637	.4295*	.5636**	.0904	-.0131	.1250	-.0535	-.2184	1.0000	.1050	.1796	.2505	.3580*
MGUR	.7035**	-.0844	-.0217	.2174	.0005	.3828*	.6000**	.5208**	.1050	1.0000	.6553**	.5891**	.7097**
CLIDUR	.8304**	-.1133	.0706	.4601**	.2980	.2564	.7724**	.5423**	.1796	.6553**	1.0000	.7733**	.7689**
SSO4UR	.8587**	-.0504	.2010	.3913*	.2084	.2980	.6814**	.4404**	.2505	.5891**	.7733**	1.0000	.7930**
ALKT	.9584**	-.0362	.4361**	.5785**	.3703*	.2527	.6578**	.4941**	.3580*	.7097**	.7689**	.7930**	1.0000
ASUT	-.0719	-.0476	-.2789	-.1669	-.3404*	-.2482	.0697	.2269	-.2470	.1897	.0844	.0274	-.0900
CDUT	-.0167	-.0278	.3551*	.0197	.1234	-.2598	-.2173	.1331	.1688	-.1674	-.0711	-.0012	.0050
CUUT	.4719**	-.0778	-.1768	.3670*	.1208	.4750**	.4844**	.3286	-.1132	.5682**	.4506**	.4766**	.3967*
FEUT	.0028	-.1330	-.5713**	-.1221	-.1358	.3200	.1872	.0393	-.2532	.1311	.1183	.0516	-.1301
MNUT	-.3010	-.1618	-.5864**	-.0396	.0033	.2778	.0094	-.1604	-.3835*	-.3596*	-.1973	-.1964	-.4917**
NIUT	.2751	.0395	-.4922**	.0458	-.0107	.3621*	.4221*	.1445	-.0590	.5039**	.2692	.1047	.2210
PBUT	.1222	-.0425	-.4229*	-.1277	-.0771	.1721	.4282*	.3353	-.3434*	.3254	.2499	.1377	.0338
ZNUT	.2498	-.2234	-.7200**	-.0391	-.0549	.3490*	.6484**	.2146	-.3745*	.3496*	.3937*	.3522*	.0471

Minimum pairwise N of cases: 46 1-tailed Signif: * - .01 ** - .001

TABLE 12

INTERPARAMETER CORRELATIONS
involving low-level metals parameters

1991 Cornwall low-level metals survey

Correlations:	ASUT	CDUT	CUUT	FEUT	MNUT	NIUT	PBUT	ZNUT
ASUT	1.0000	-.2130	.1316	.2099	-.0298	-.0256	.1326	.2068
CDUT	-.2130	1.0000	-.1001	.0739	.0925	-.2692*	-.3736**	-.3554**
CUUT	.1316	-.1001	1.0000	.2955*	.1501	.3120*	.2509*	.3760**
FEUT	.2099	.0739	.2955*	1.0000	.6425**	.2135	.0276	.3504**
MNUT	-.0298	.0925	.1501	.6425**	1.0000	.0533	-.0945	.3448**
NIUT	-.0256	-.2692*	.3120*	.2135	.0533	1.0000	.2746*	.5195**
PBUT	.1326	-.3736**	.2509*	.0276	-.0945	.2746*	1.0000	.4670**
ZNUT	.2068	-.3554**	.3760**	.3504**	.3448**	.5195**	.4670**	1.0000

Minimum pairwise N of cases: 91   1-tailed Signif: * - .01 ** - .001

The major factor group obtained included conductivity, sodium, potassium, magnesium, chloride, sulfate, alkalinity, and copper, all of which are highly correlated with each other. These parameters are characteristic of background St. Lawrence river water and do not have large inputs from any one source in the Cornwall-Massena area. However, their spatial variation does indicate some transport patterns in the area.

Figure 5 shows the transport pattern of chloride. In figure 5, as well as subsequent similar figures, stations north of Cornwall Island are connected by dotted lines, and those to the south by solid lines. A dashed line connects stations 479, 437, and 444 (transport between Cornwall and St. Regis Islands). As a result of inputs from Domtar/ICI/Cornwall Chemicals and Courtaulds, higher chloride concentrations are found in the north channel at stations 476 and 431, and continue downstream to 436 and 444. Stations 477 and 443 are also affected by Cornwall WPCP and storm sewers, and display higher values as a result. On the other hand, the south channel stations 478 and 479, which are close to the U.S. shore, display lower concentrations, as a result of mixing with waters from the Grasse and Raquette River. The impact of the St. Regis and Raquette rivers, flowing along the south shore of the St. Lawrence River, is also felt at station 402; station 441 is also affected by the St. Regis River, and displays the lowest level of most conventional water quality parameters found at any station in the main river channels. Station 437, between Cornwall and St. Regis Islands, contains water that has travelled through the south channel. Its concentration for many parameters (e.g. conductivity; Figure 6) is higher than those at stations 478 and 479, however, probably as a result of lateral heterogeneity in the south channel (water from the Grasse and Raquette Rivers presumably stays closer to the south shore than the north shore of this channel). Hydrodynamic transport model calculations (P. Nettleton, in prep.) indicate that station 444 receives water from the vicinity of station 437, as well as 436. This transport scheme is indicated by the dotted line on Figures 5-6. This general transport scheme is well enough established to be useful in calibrating the transport portion of the metals fate and transport model.

Other minor groups found by factor analysis include ammonia, DOC, iron, and manganese; total kjeldahl N, calcium, and (negatively correlated) aluminum; nickel, lead, zinc, and (negatively correlated) nitrate and cadmium; and turbidity and suspended solids. These groups do not appear to correspond to any loading combinations and are not further discussed here.

Correlations among heavy metals (Table 12) are in general weaker than those between most major ions as discussed above. Zinc correlates with most other metals (negatively with cadmium); correlations of cadmium with most metals are negative or nonsignificant, suggesting different sources and/or transport patterns for this metal.

Figure: 5

1991 CORNWALL SURVEY

CHLORIDE CONCENTRATION

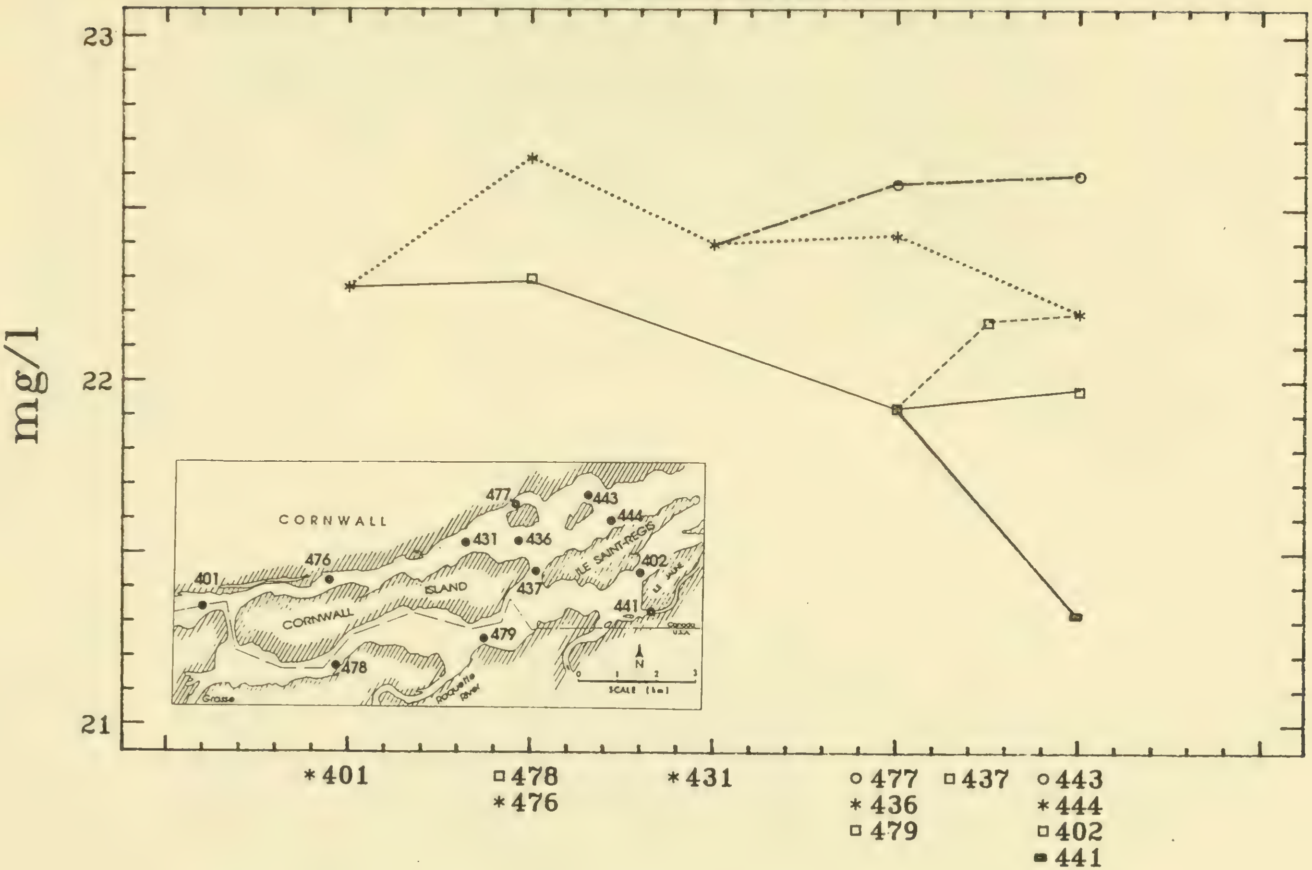
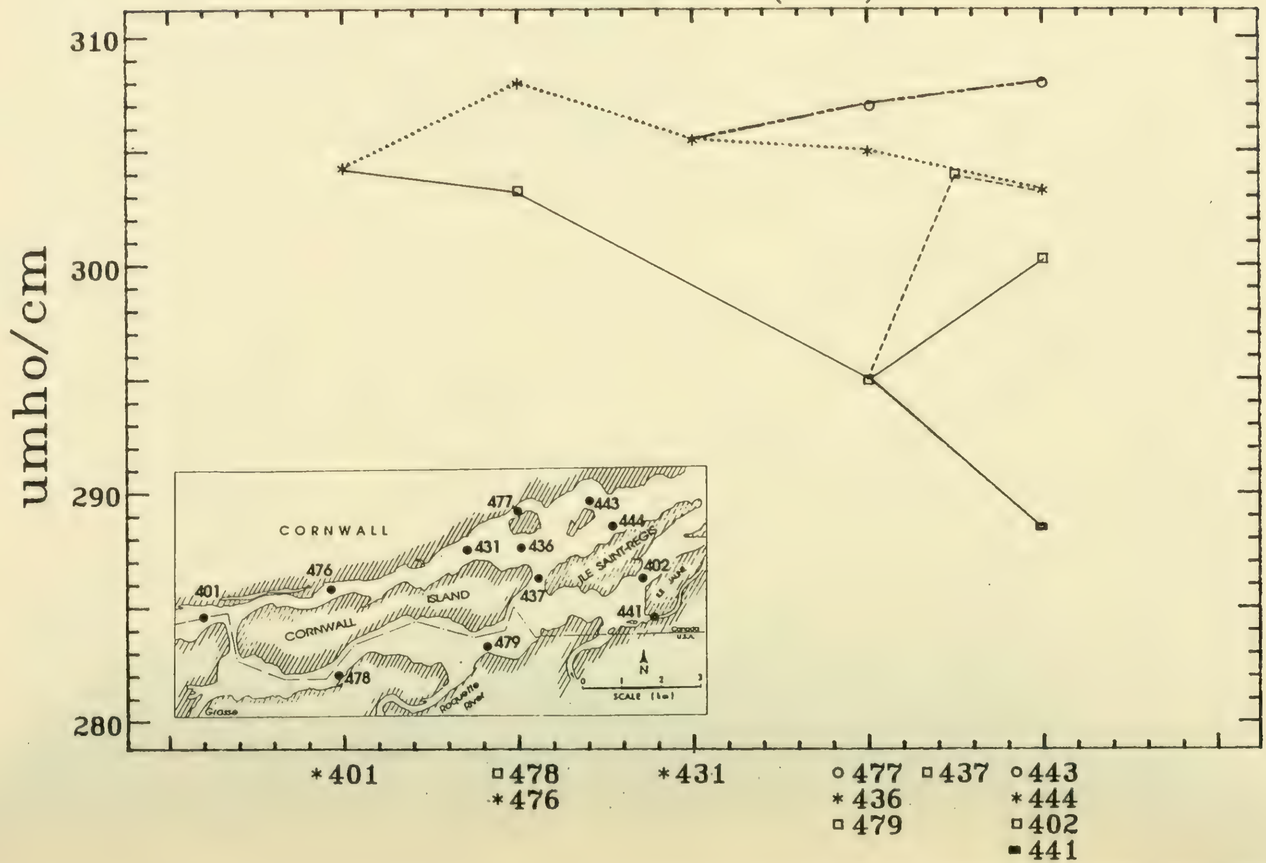


Figure: 6

1991 CORNWALL SURVEY

CONDUCTIVITY (25° C)



Spatial variations for selected metals are given for survey week 1 (July 17-19) in Figures 7 to 14. As discussed earlier, these results are believed to be more reliable than those of the second survey week. Transport patterns (P. Nettleton, in prep.) are indicated by coded lines, similar to those in Figures 5 and 6. West of the east end of Cornwall Island, spatial variations of most metals parallel those of typical conventionals. However, arsenic (Figure 7) levels are higher on the south shore, presumably because the only measurable input was from Reynolds Metals (Section 3.1). Cadmium and lead levels are similar on both sides of the river. As a result of its major input from Courtaulds, zinc levels at stations 477 and 443 are far higher than those at other stations, including 431. This is in agreement with the results of the transport model (P. Nettleton, in prep.), which shows that flows from the Courtaulds diffuser pass between this station and the north shore, to the downstream locations; sediment patterns observed in earlier work (Anderson, 1990: RAP, 1991) support this transport pattern.

East of Cornwall Island, the distribution pattern of heavy metal concentrations is less regular. At station 441 (channel between Yellow I. and Quebec shore), the concentration of most metals is at or near the lowest observed in the study area, but is highest for cadmium. Whether or not this is due to higher Cd levels in St. Regis River cannot be ascertained, as the tributary levels were only measured at conventional detection limits and were below detection. Levels at station 437 (dashed line on graphs) were often either higher or lower than expected; for several metals, there is a closer resemblance of metal levels between stations 401 and 437 (e.g As, Cu, Fe). This suggests a horizontally stratified transport in the south channel, with upstream water being transported close to Cornwall Island and thence through the gap north of St. Regis Island. Such a transport pattern is also suggested by the calibrated dispersion model (P. Nettleton, in prep.) These transport phenomena will be studied further with the heavy metals transport model. (D. Poulton, in prep.).

While no mercury samples were collected during this survey, some samples were obtained by Richman (in prep.) in 1988 and 1991, and analyzed at the Dorset laboratory using methods described by Mierle (1990). The detection limit is limited by variation of mercury levels in the blanks (Mierle, 1990), and is typically about 0.2 to 0.3 ng/L. Levels in 1988 ranged from 0.3 to 0.9 ng/L, and in 1991 from 2.0 to 3.5 ng/L. No particular spatial distribution was evident. Richman (in prep.) suggested that contamination of the 1991 samples might have occurred, but could not offer any other explanation for the between-year difference.

A comparison of metal results may also be made with those obtained in Environment Canada surveys of recent years (Table 1) (Anderson and Bieberhofer, 1990, 1991). This shows that most metal levels are similar to those found recently. Nickel levels, however, are somewhat

Figure 7

1991 Cornwall survey

Total arsenic concentration, week 1

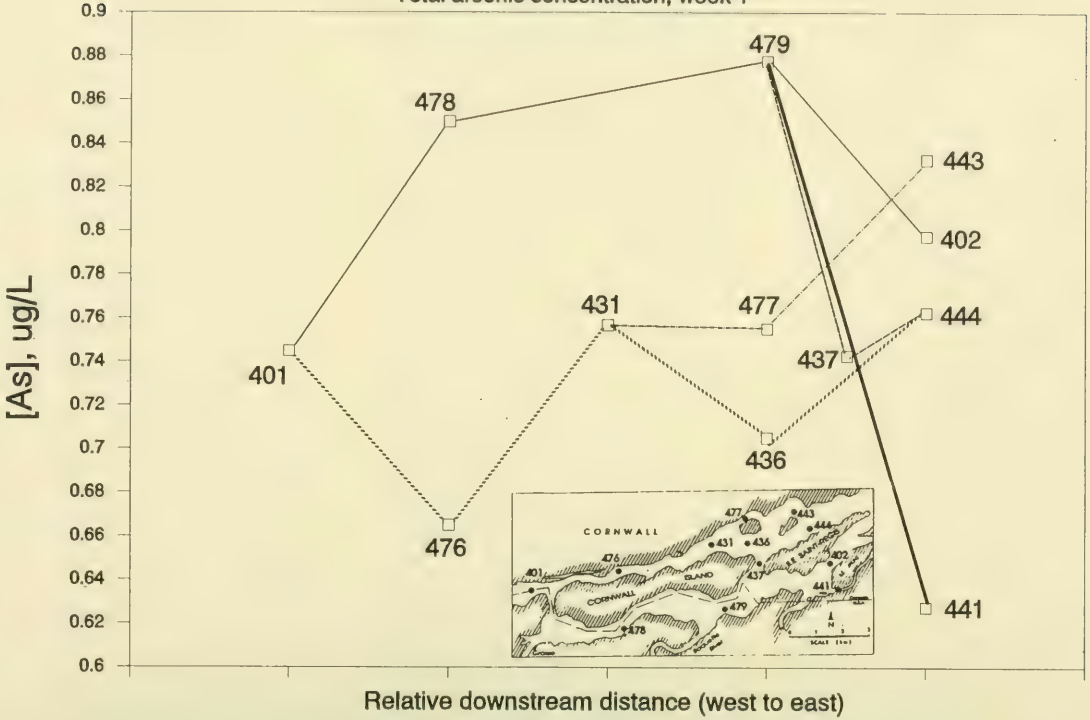


Figure 8

1991 Cornwall survey

Total cadmium concentration, week 1

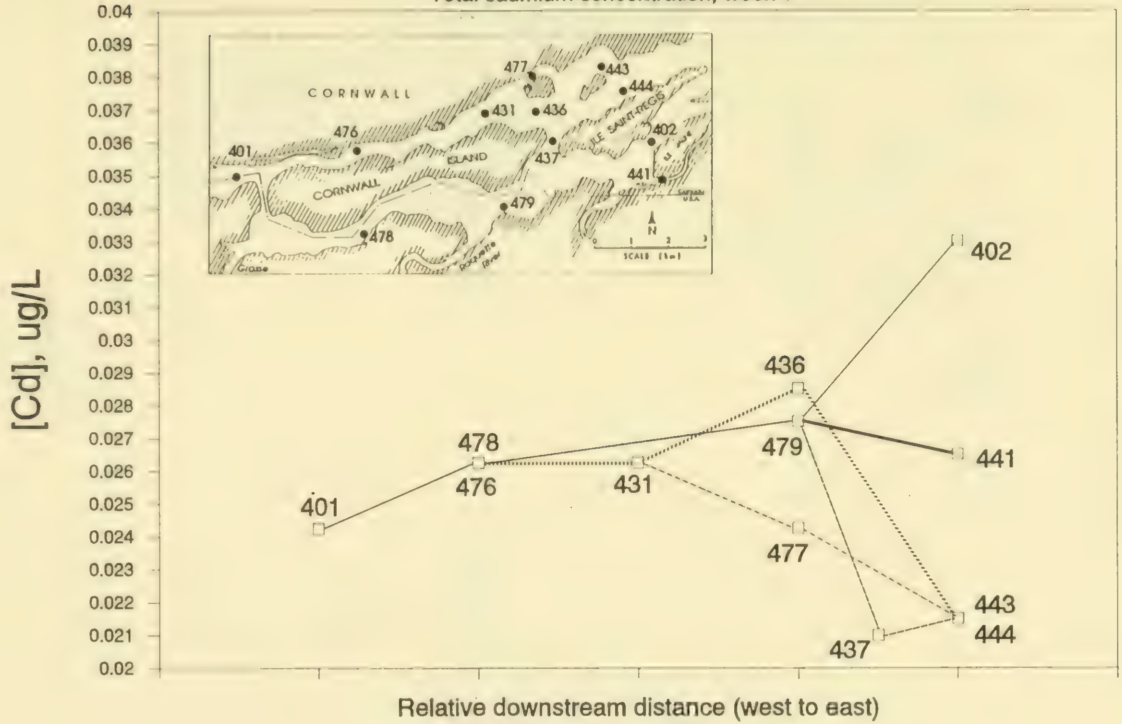


Figure 9

1991 Cornwall survey

Total copper concentration, week 1

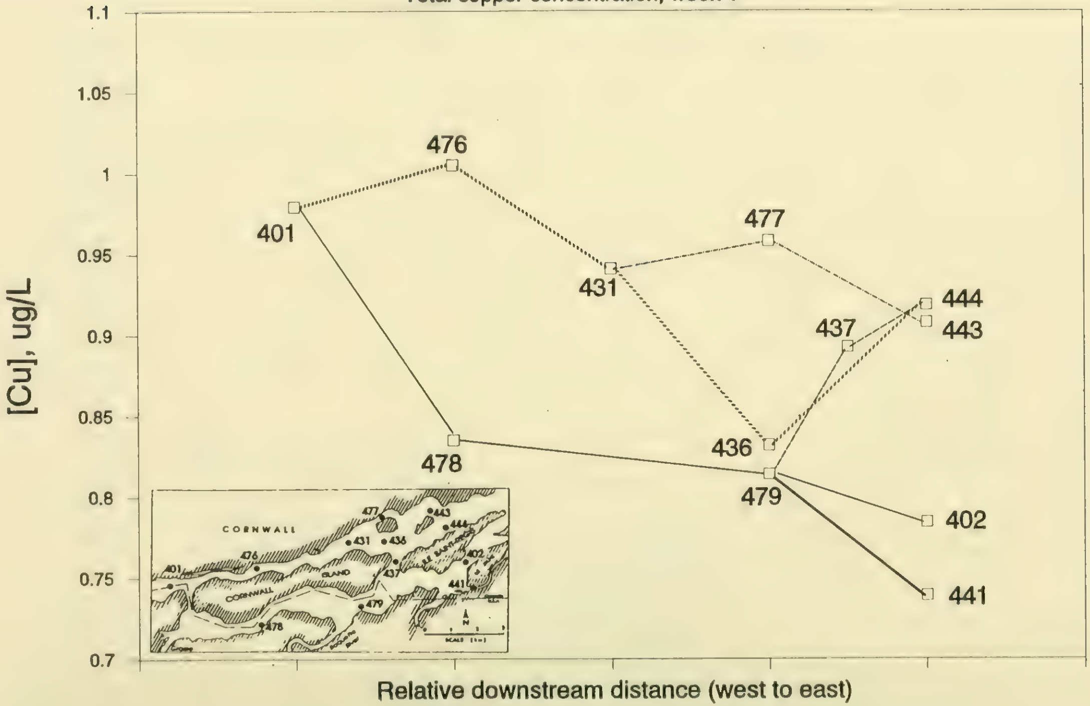


Figure 10

1991 Cornwall survey

Total iron concentration, week 1

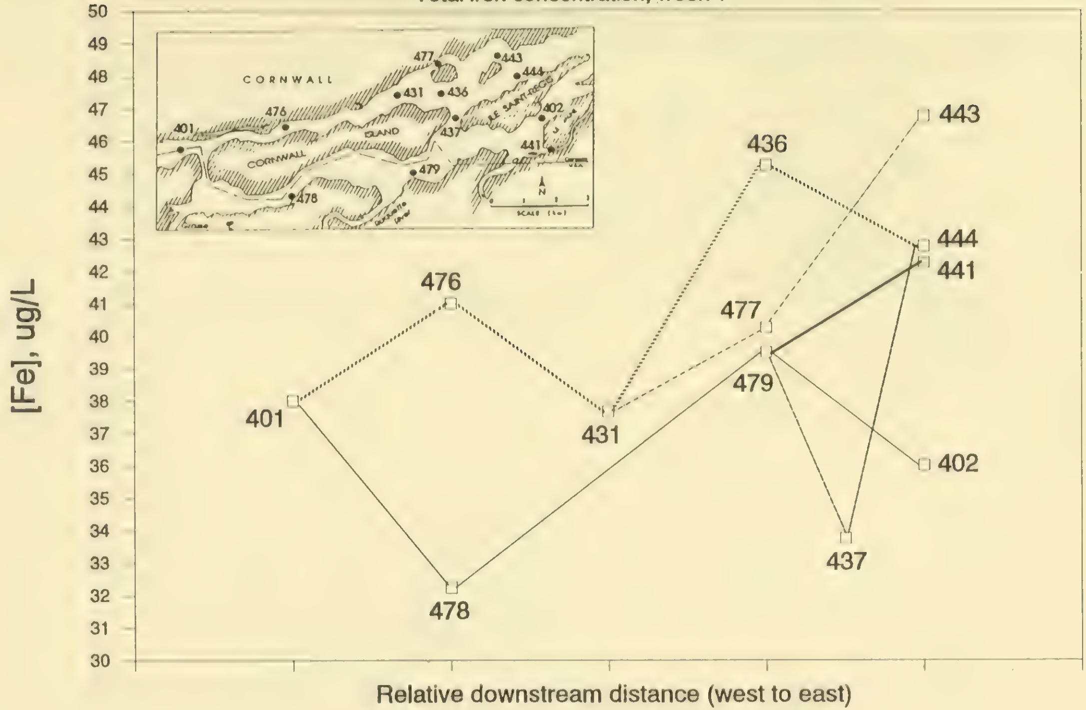


Figure 11

1991 Cornwall survey

Total manganese concentration, week 1

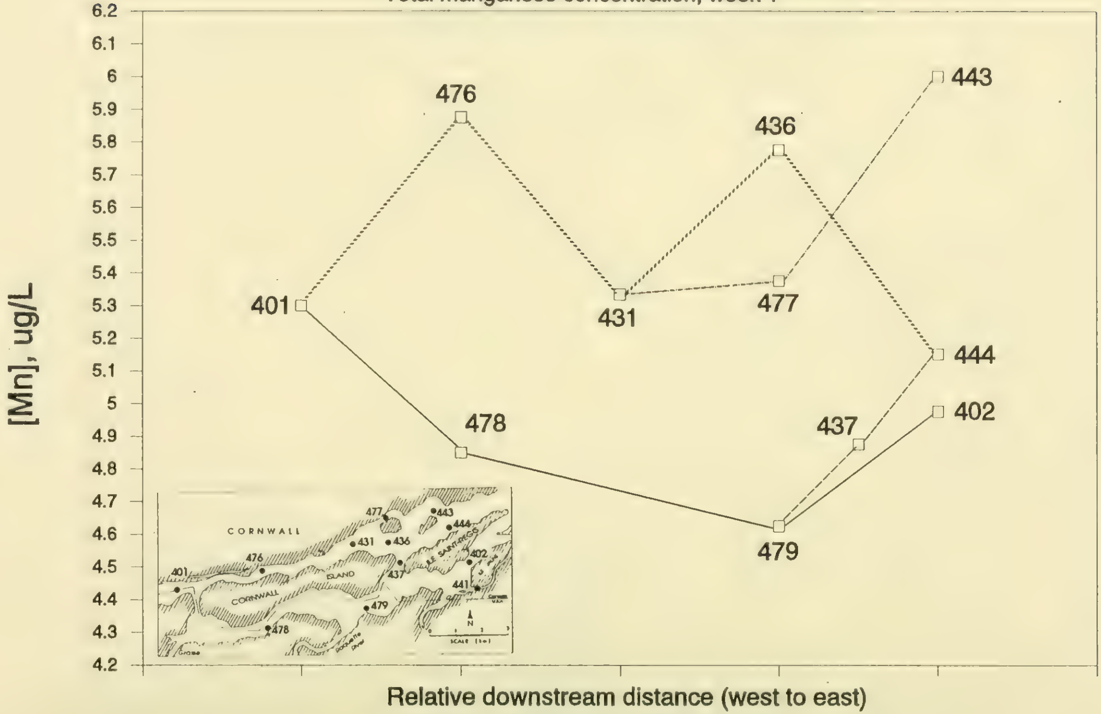


Figure 12

1991 Cornwall survey

Total nickel concentration, week 1

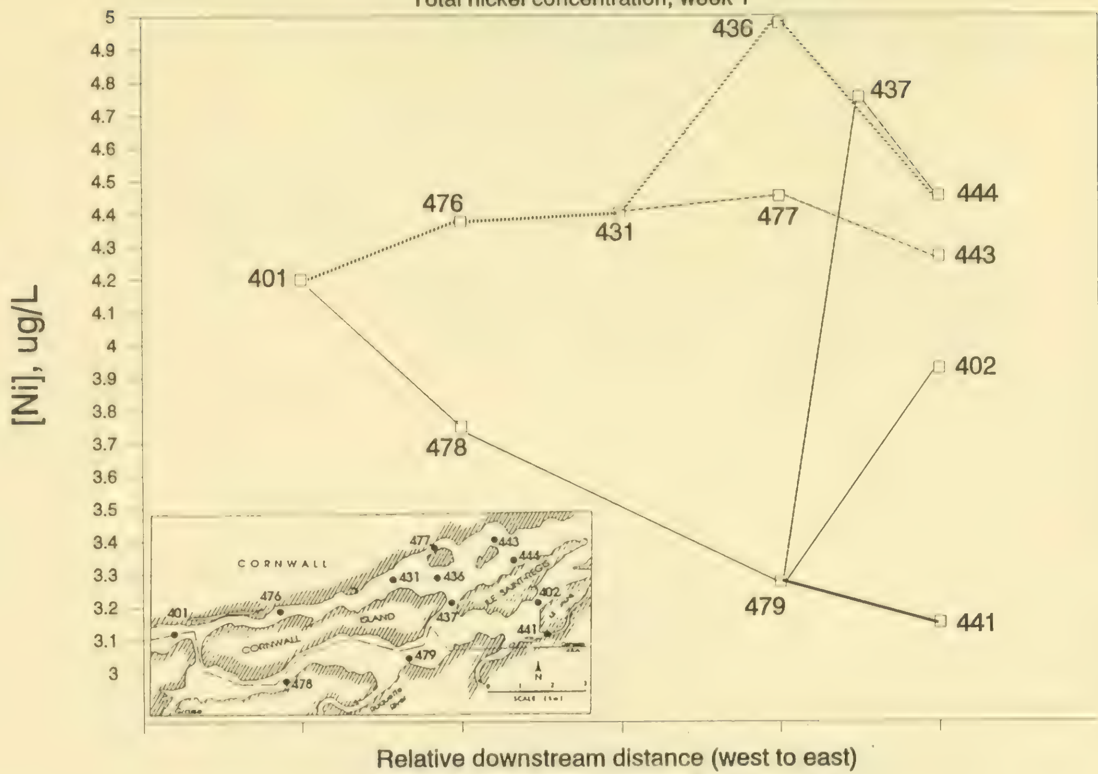


Figure 13

1991 Cornwall survey

Total lead concentration, week 1

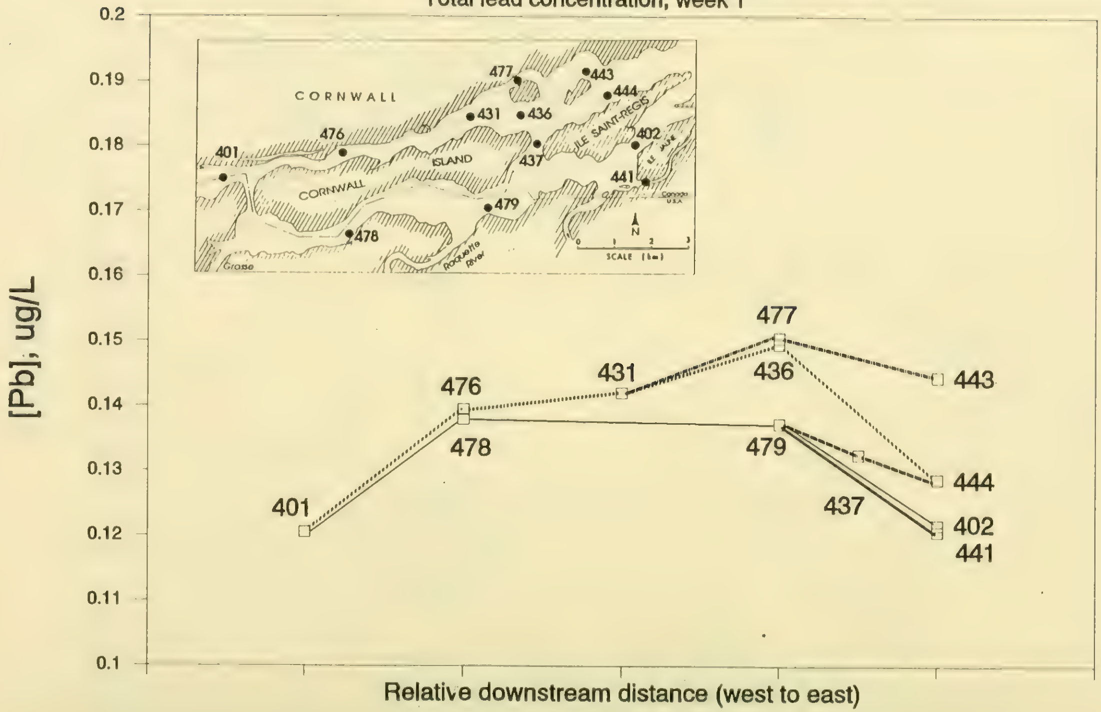
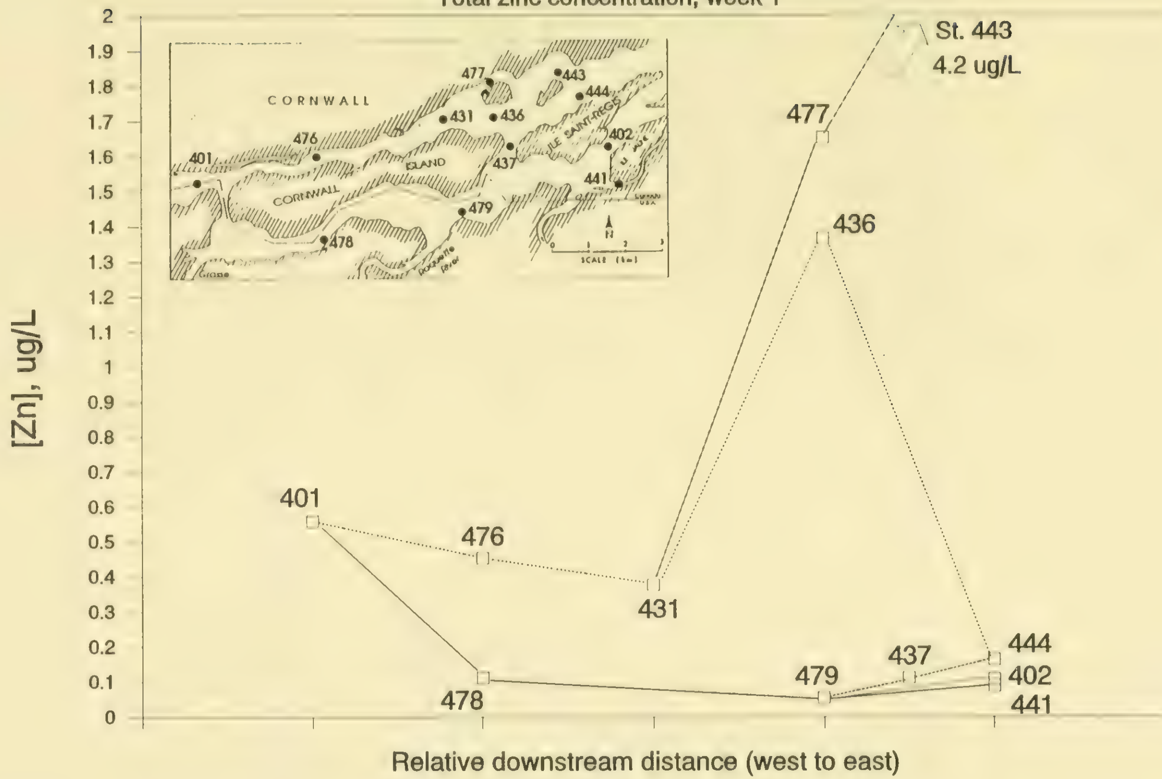


Figure 14

1991 Cornwall survey

Total zinc concentration, week 1



higher in 1991; the reason for this is unknown. Zinc levels (if week 1 results are used) are lower, reflecting the continued decrease in inputs. Results for cadmium and lead were quantified for the first time in this study, as earlier data were mainly "non-detect". All low-level metal data measured in this survey were below relevant Provincial Water Quality Objectives (PWQO).

3.3 Sediment Results

Both suspended and bottom sediments were collected in order to characterize the solids with which the river is in equilibrium, for purpose of the metals model. Use of sediment traps to collect suspended sediments provided a time-integrated level of suspended metal levels over the survey period.

Duplicate sediment trap samples were obtained in July 1991 from the 12 in-river and three tributary mouth locations (Figure 3). Details of sediment trap construction, deployment and retrieval, and the characteristics of materials collected are given elsewhere (Tarandus, 1991). In brief, sediments at stations 401, 431, 441, 443, 476, 477, 478, and 15-04 were observed to be dominated by sand with some silt and/or gravel. Silt was observed to be dominant at stations 402, 436, 437, 444, 479, 15-02, and 15-03. The highest sedimentation rates, inferred from masses of samples collected were at station 431 (151 and 144 g/m^2-day), 441 (137 and 130 g/m^2-day), 401 (119 and 144 g/m^2-day), and 479 (114 and 123 g/m^2-day). Station 431 is downstream of the Domtar/ICI/Cornwall Chemicals and Courtaulds outfalls and is influenced by these sources. Station 401 is at the upstream end of the study area, just downstream of the Moses-Saunders hydroelectric dam. Station 441 is in a small channel east of the mouth of the St. Regis River that carries only a small fraction of the river flow.

The lowest sedimentation rates (<20 g/m^2-day) were found at the mouths of the Grasse and Raquette Rivers; presumably high water flow inhibits settling of solids at these locations. Some storm impact was suggested by the variable results recorded by the U.S. Geological Survey gauge on the Raquette River; average flows ranged from 579 to 1440 ft^3/s during the trap deployment. Further data on weights of sediment collected and sedimentation rates is given in Tarandus, 1991.

Both bottom and trap samples were analyzed for conventionals, heavy metals and particle size as described in Section 2; due to limited laboratory resources, only one sample of each bottom replicate pair was analyzed for particle size. The raw data thus obtained, and particle size histograms, are given in Appendix D.

Sediment Sample Zonation

Zones representing sediment samples of similar origin were defined by ratio matching and cluster analysis (Poulton, 1989). This method helps to identify pollutant sources by identifying sediment samples of similar origins. Unique samples (of different origin from most) can be related to nearby sources. The technique is based on the fact that sediment samples of similar origin tend to have similar ratios of concentrations of anthropogenic pollutants, even though they may be diluted with varying amounts of inert background materials such as silica, calcite, etc. The similarity matrix is broken down into groups representing similar stations by cluster analysis (Poulton, 1989). This procedure was conducted separately on the data from the suspended and bottom sediments. Parameters used included all heavy metals, TKN, TP, TOC, and LOI (trap samples). Due to several "non-detected" results, Cd and Hg were omitted from the bottom sediment clustering only. Results of this clustering are shown in Figures 15 and 16 for the two data sets, respectively. Average concentrations of conventionals and heavy metals are given for suspended and bottom sediments in each zone in Tables 13-14. Values for the new Provincial Sediment Quality Guidelines (Persaud et al., 1991) are shown for comparison.

Average concentrations of heavy metals, N, P, and C are higher by a factor of 1.5 to 4 in the sediment traps compared to the bottom sediments. This is because the high-energy environment created by the strong river flow sweeps most of the contaminated fine-grained particles downstream towards Lake St. Francis; thus bottom particles are depleted in fines. Cluster analysis of the trap samples reveals four groups: group 1 contains all locations located along the main flow zone of the river, between Cornwall Island and the New York shore, and extending north and south of St. Regis Island. Group 2 consists of five stations along the Ontario shore downstream from the major discharge points. These are distinguished from Group 1 by higher levels of several metals, most notably Zn. The 1988 Environment Canada survey (RAP, 1991) showed that the Courtaulds plants had the highest levels of Hg, Zn, Cu, and Pb in effluents suspended solids, collected by centrifuge; the impact on the river suspended solids is indicated by the observed higher levels of these metals in Group 2. Again, this is similar to predictions of flow distributions obtained with the hydrodynamic/dispersion model (P. Nettleton, in prep.) Groups 3 and 4 are the mouths of the Grasse and St. Regis Rivers on the New York side, respectively. They have higher than average levels of most metals, most notably iron and manganese (generally considered to be nonanthropogenic and related to watershed mineral composition). Group 4 is distinguished from group 3 by lower Cu and Hg, and higher LOI and TOC. Particle size distributions (Appendix D) are similar for all groups, with the peaks occurring in the fine silt to coarse clay range. High organic levels in these samples precluded use of the coarse microtrac analyzer (Laboratory Services Branch, pers. comm.); however, it

FIGURE 15: ZONATION OF SUSPENDED (TRAP) SEDIMENTS BASED ON RATIO MATCHING AND CLUSTER ANALYSIS, CORNWALL, 1991

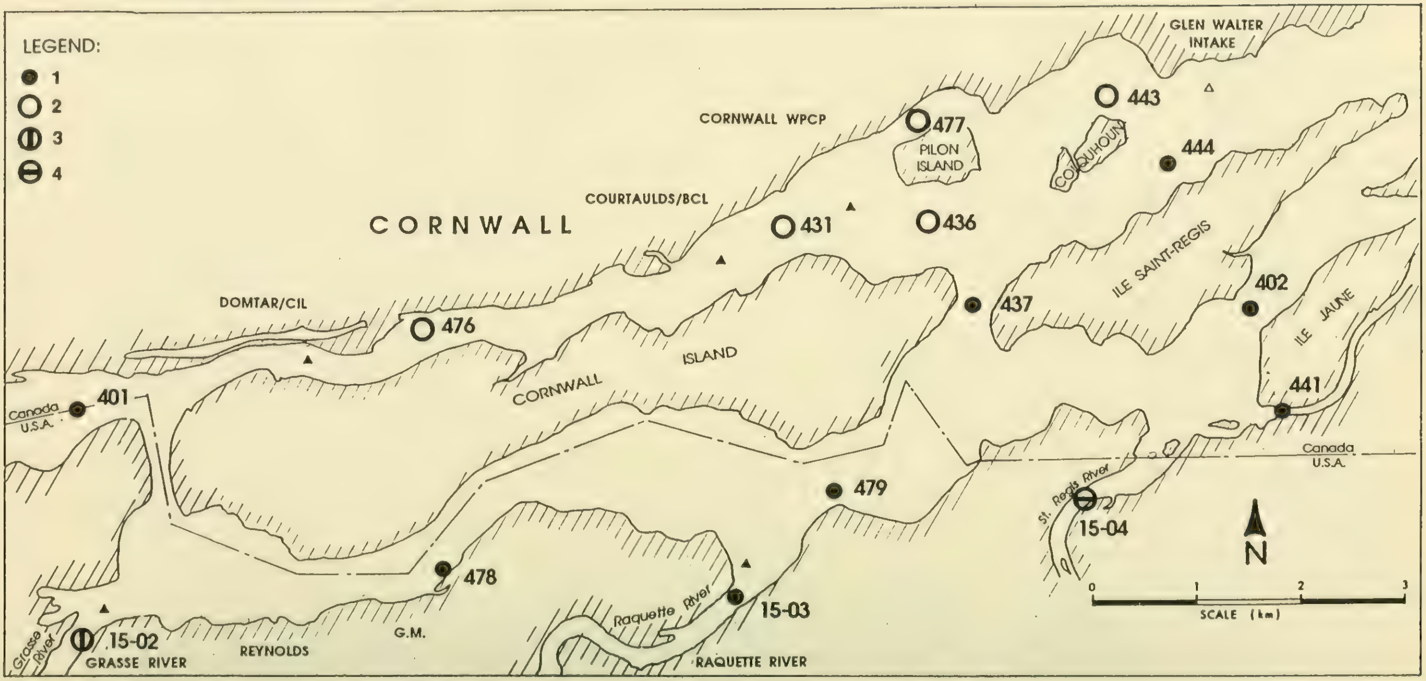


FIGURE 16: ZONATION OF BOTTOM (GRAB) SEDIMENTS BASED ON RATIO MATCHING AND CLUSTER ANALYSIS, CORNWALL, 1991

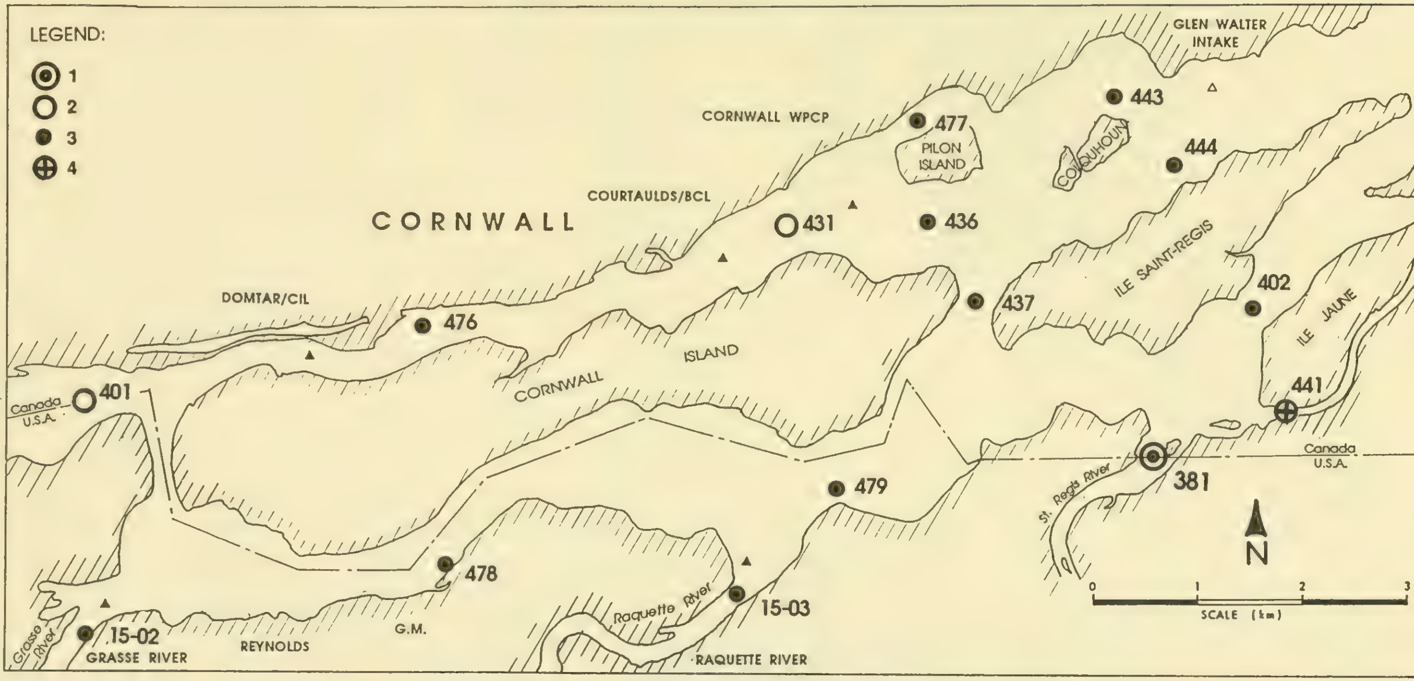


TABLE 13

MEAN 1991 CORNWALL SEDIMENT GENERAL CHEMISTRY DATA BY CLUSTER

Cluster		# samples	TKN	Total P	Loss on Ignition	Total Organic Carbon	Al	Ca	Mg
(a) Sediment trap samples									
all	mean	30	6.6	1.94	112.	52.	19.2	43.	12.2
	sd		1.3	0.47	27.	12.	2.0	14.	1.2
1	mean	16	6.0	1.81	97.	46.	18.6	47.	12.7
	sd		1.3	0.40	13.	7.	1.8	7.	0.4
2	mean	10	7.2	1.82	113.	52.	18.8	51.	12.6
	sd		0.7	0.19	8.	2.	1.1	2.	0.2
3	mean	2	7.6	2.85	130.	61.	23.0	11.	10.3
	sd		0.4	0.21	14.	4.	1.4	1.	0.2
4	mean	2	8.2	2.70	195.	88.	22.5	9.	8.5
	sd		0.1	0.57	7.	0.	0.7	1.	0.1
(b) Bottom sediment grab samples									
all	mean	29	2.5	0.98	-	20.	11.7	30.	11.2
	sd		2.1	0.33	-	15.	0.7	16.	4.4
1	mean	2	0.58	0.57	-	7.3	4.7	5.	3.0
	sd		0.0	0.13	-	1.1	0.4	1.	0.4
2	mean	4	2.9	0.76	-	4.5	6.1	30.	9.8
	sd		4.0	0.15	-	1.3	3.5	20.	4.9
3	mean	21	2.7	1.07	-	25.	11.7	33.	11.3
	sd		1.7	0.34	-	14.	5.0	15.	2.8
4	mean	2	0.64	0.99	-	3.5	30.5	31.	20.5
	sd		0.03	0.02	-	1.3	0.7	11.	0.7
Provincial Sediment Quality Guidelines:									
		LEL	0.55	0.6	-	10.	-	-	-
		SEL	4.8	2.0	-	100.	-	-	-

Note: All results are in mg/g.

TABLE 14

MEAN 1991 CORNWALL SEDIMENT HEAVY METAL DATA BY CLUSTER

Cluster		# samples	As	Cd	Cr	Cu	Fe (mg/g)	Hg	Mn	Ni	Pb	Zn
(a) Sediment trap samples												
all	mean	30	5.7	1.69	42.2	48.2	24.6	0.23	960.	30.8	31.1	215.
	sd		1.1	0.20	6.4	16.5	5.5	0.14	940.	2.9	5.0	115.
1	mean	16	4.9	1.67	39.3	44.1	23.0	0.13	680.	30.8	28.4	144.
	sd		0.6	0.19	3.8	11.6	1.8	0.02	90.	2.6	3.8	18.
2	mean	10	6.2	1.65	41.7	59.6	21.9	0.40	510.	31.0	33.9	331.
	sd		0.6	0.14	3.0	17.9	1.1	0.12	70.	2.0	4.6	133.
3	mean	2	8.0	1.65	55.0	50.5	36.0	0.24	2550.	35.0	34.0	190.
	sd		0.3	0.21	7.1	3.5	1.4	0.01	350.	4.2	7.1	14.
4	mean	2	7.1	2.05	55.5	22.0	39.5	0.16	3850.	26.0	36.0	230.
	sd		0.1	0.35	0.7	0.0	0.7	0.01	350.	1.4	2.8	0.
(b) Bottom sediment grab samples												
all	mean	29	2.6	0.44	25.7	23.5	17.5	0.13	320.	16.2	17.1	123.
	sd		1.4	0.40	12.8	16.8	7.6	0.17	180.	8.6	11.4	108.
1	mean	2	0.9	ND	11.5	2.9	14.5	ND	190.	4.8	2.6	51.
	sd		0.1	-	0.7	0.7	0.7	-	10.	0.1	1.1	1.
2	mean	4	1.3	ND	16.4	10.1	14.0	0.02	220.	10.0	6.8	50.
	sd		0.3	-	7.8	6.4	6.6	0.02	100.	4.7	2.8	30.
3	mean	21	2.8	0.57	25.9	27.0	16.5	0.18	320.	16.7	21.1	145.
	sd		1.2	0.39	9.4	16.9	5.4	0.18	150.	6.4	10.8	119.
4	mean	2	4.9	0.25	56.5	35.0	37.5	ND	760.	36.0	10.4	110.
	sd		0.1	0.25	2.1	2.8	2.1	-	40.	1.4	2.3	0.
Provincial Sediment Quality Guidelines:												
		LEL	6	0.6	26	16	20	0.2	460	16	31	120
		SEL	33	10	110	110	40	2	1100	75	250	820

Note: All results are in μg/g unless otherwise stated.
"ND" = not detected, below 0.05 (Cd) or 0.01 (Hg) μg/g.

is apparent from the size distributions that this fraction would constitute only a very small fraction of the total sample. At any rate, suspended material rarely contains much if any sand (D. Boyd, pers. comm.)

The ratio matching/cluster analysis method likewise yielded four clusters with the bottom samples (Figure 16). However, the interpretation is not as simple. Stations 381 (mouth of St. Regis River) and 441 (channel between Yellow Island and Quebec mainland) were individual clusters (groups 1 and 4, respectively); stations 401 (upstream) and 431 (below Courtaulds) clustered together (group 2), while all remaining locations comprised one large group (group 3). Station 441 (group 4) was distinguished by high values of several metals (Cr, Fe, Mn, Ni); it also had much higher amounts of clay than all other bottom samples, probably because the small channel carries a much slower current and permits deposition of such fines. Conversely, station 381 (group 1) is nearly all sand and has much lower levels of most metals, especially Cr, Cu, Ni, Pb, Zn, as well as nondetectable levels of Hg and Cd. Group 2 is distinguished by lower than average levels of most metals (but higher than group 1), except for Fe, Zn, and Cd (non-detected), which were similar to group 1. Group 3 is distinguished by its larger TOC content; most stations in this group show a longer-distance effect of point source plumes (again, also suggested by the dispersion model); thus they have slightly higher than average contaminant levels.

Sediment Particle Size Distributions

Most bottom sediment samples showed a bimodal particle size distribution, with a (for most) large medium to coarse sand fraction and a smaller silt-clay fraction (Appendix D). The shape of the small fraction distribution was similar to that of the trap samples. This suggests that the samples are a composite of glacial sands with a small but varying proportion of anthropogenically-derived fines (more fines at stations 436, 443, and 479). The latter would be deposited and re-suspended as the river currents changed, and could also be obtained in variable amounts dependent upon the penetration of the Shipek sampler. Group 2 samples showed a smaller amount of silt and clay than group 3; however, as stated above, individuals in group 3 presented a large range of distributions. Station 441 (group 4) showed only a very small amount of sand mixed with the characteristic group of fines. At 15-02 (described by the field crew as "ooze"), high organics precluded coarse sample analysis (as with trap samples).

Forstner and Wittmann (1983) have demonstrated a link between sediment grain size and concentrations of at least some metals, with high metal levels being associated with fine-grained particles. Mudroch and Duncan (1986) found that most metals of anthropogenic origin in the Niagara River sediments were associated with particles < 13 μm in diameter. A correction for

grain size may be developed by correlating metal levels in bottom sediments with cumulative fractions of particles below certain size ranges. Such correlations showed highly significant relationships with the highest correlation coefficients being found for fractions below 10.5 to 88 μm, depending upon the metal. For metals such as nickel, where only small inputs occur within the study area, very high correlations are found (Figure 17). The correlation is lower for metals such as mercury and zinc, where significant inputs are known to occur. When these correlations are plotted (Figures 18-19), it is observed that stations downstream of point sources have higher concentrations than expected on a straight-line basis. Thus stations 443 and 477 have higher-than-expected mercury and zinc levels (note that station 477 lies above the most of the points for zinc, despite its low zinc level). These are consistent with the known input from Courtaulds (Tables 4-5). Station 476, downstream of Domtar/ICI/Cornwall Chemicals, has higher than expected mercury (but not zinc) levels, also consistent with its input from this source. Station 436 shows an intermediate mercury level, consistent with downstream transport and dilution effects. Therefore, despite the transient nature of the contaminated fine-grained particles, an impact of the pollution discharges can be seen on the bottom samples.

Grain-size corrected metal levels are computed by dividing the observed metal levels by the fraction of particles below the size with the highest correlation. These are given in table 15.

Station 381 is omitted from this table due to its negligibly small fine-grain fraction, and station 437 due to lack of grain-size data. Again, stations downstream of the inputs demonstrate generally higher corrected metal levels (e.g. stations 431, 443, 476, 477). This also shows the effect of Courtaulds discharges on zinc levels (corrected zinc level of about 900 μg/g at station 477, but low corrected zinc at station 476), contrasted to that of Domtar/ICI for mercury (corrected mercury levels above 1 μg/g at both stations 476 and 477). These methods, as well as the cluster analysis on the suspended sediment data, indicate the effects of the discharges on the metal regime in the St. Lawrence River.

<u>Comparison of Sediment Results with Guidelines and Previous Data</u>

Comparison of average sediment trap contaminant levels with the Provincial Sediment Quality Guidelines indicated that most of the metal concentrations exceed the Lowest Effect Level (LEL); average levels of TKN throughout, and Mn and total P in zones 3 and 4 exceed the Severe Effect Level (SEL). The criteria of Persaud et al. (1991) indicate that the suspended matter is highly contaminated and will likely have a significant effect on benthic biota. However, this effect should be felt mainly at downstream (Lake St. Francis) depositional areas. The bottom sediments exceed the LEL for several of the metals studied; however, except for Zn they are below the "background" levels for Great Lakes pre-colonial sediment horizon quoted by Persaud et al. (1991). Zn levels in

TABLE 15

GRAIN-SIZE CORRECTED SEDIMENT METAL LEVELS

Station	As	Cd	Cr	Cu	Fe (mg/g)	Hg	Mn (mg/g)	Ni	Pb	Zn
401	11.0	.27	120.	52.	129.	.08	1.84	75.	30.	270.
401	11.0	.27	85.	40.	93.	.08	1.38	53.	39.	210.
402	6.3	.39	67.	46.	69.	.13	.88	42.	29.	254.
402	6.7	.84	60.	46.	64.	.03	1.24	39.	29.	254.
431	11.9	.30	190.	113.	239.	.32	3.20	106.	61.	523.
431	8.6	.36	139.	93.	205.	.13	2.52	73.	55.	470.
436	6.8	.86	64.	57.	51.	.50	.75	38.	50.	274.
436	5.7	.94	55.	49.	48.	.45	.72	33.	34.	238.
441	6.4	.57	73.	44.	48.	.01	1.05	46.	16.	147.
441	6.7	.09	77.	49.	52.	.03	.97	49.	12.	147.
443	8.8	1.43	70.	68.	53.	.76	.80	41.	55.	724.
443	8.3	1.43	71.	69.	53.	.73	.80	43.	53.	740.
444	7.1	1.13	63.	56.	59.	.09	.88	44.	35.	209.
444	4.9	.71	51.	40.	52.	.06	.79	33.	20.	142.
476	7.7	.13	84.	98.	79.	1.02	1.13	50.	64.	246.
476	8.0	.60	84.	83.	84.	1.05	1.08	50.	50.	234.
477	20.0	.36	148.	186.	156.	.88	2.79	97.	77.	1034.
477	11.7	1.00	133.	110.	133.	1.60	2.21	83.	83.	828.
478	7.0	1.27	74.	49.	72.	.14	1.34	42.	38.	208.
478	7.0	.67	78.	56.	72.	.05	1.34	42.	35.	204.
479	6.3	1.19	65.	47.	68.	.12	.95	34.	32.	223.
479	6.1	.90	65.	47.	72.	.16	1.10	37.	37.	243.
2	5.3	1.87	64.	92.	68.	.23	1.49	36.	56.	333.
2	5.6	1.73	64.	91.	64.	.20	1.28	37.	55.	320.
3	5.5	.84	79.	50.	109.	.18	1.57	28.	50.	466.
3	5.1	.49	70.	34.	88.	.18	1.45	27.	43.	466.

Note: All concentrations are in $\mu g/g$, unless otherwise noted.

Figure 17

Correlation of sediment nickel levels with grain size

1991 Cornwall survey

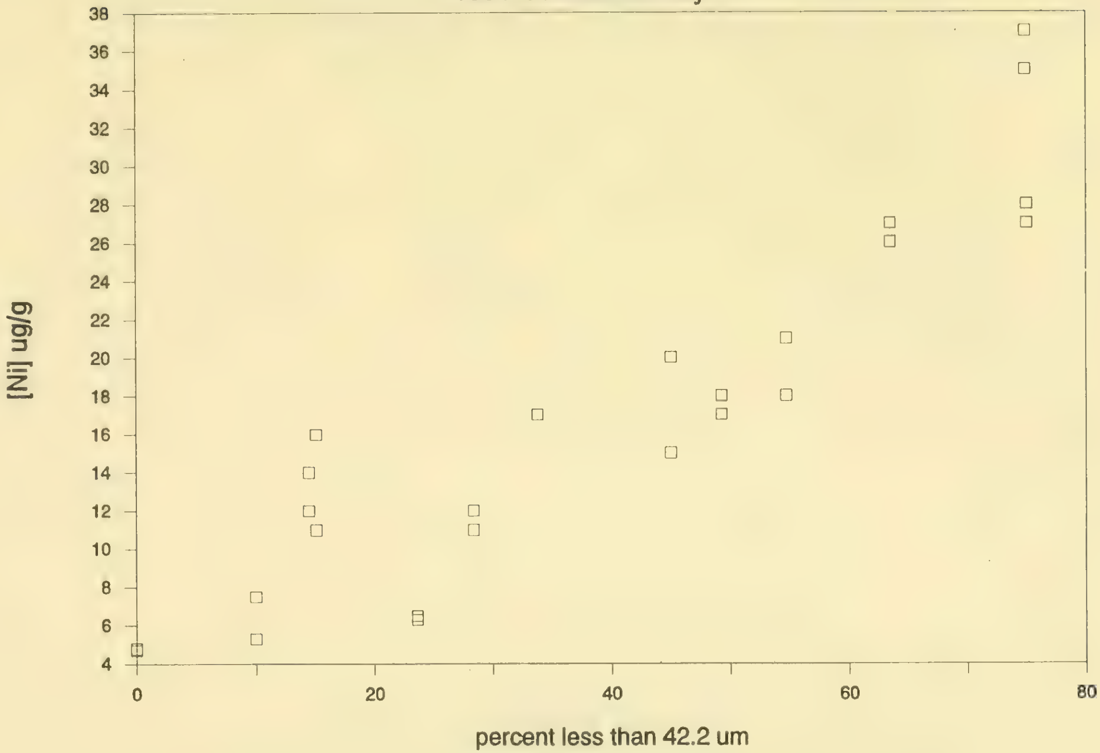


Figure 18

Correlation of sediment mercury levels with grain size

1991 Cornwall survey

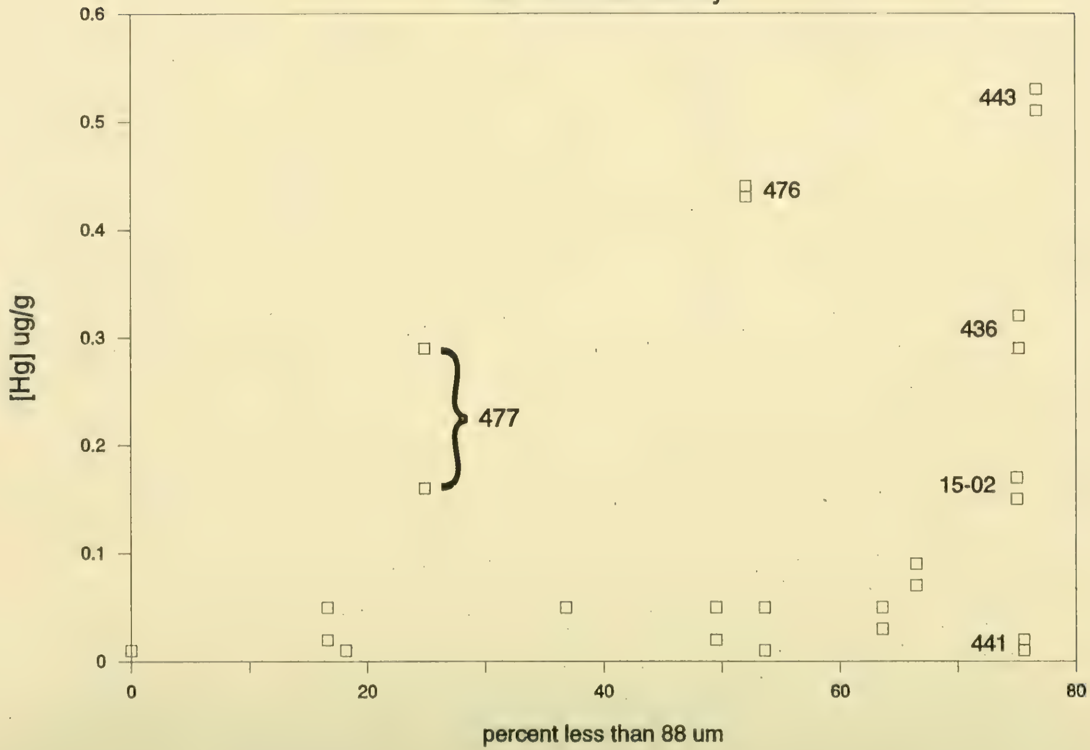
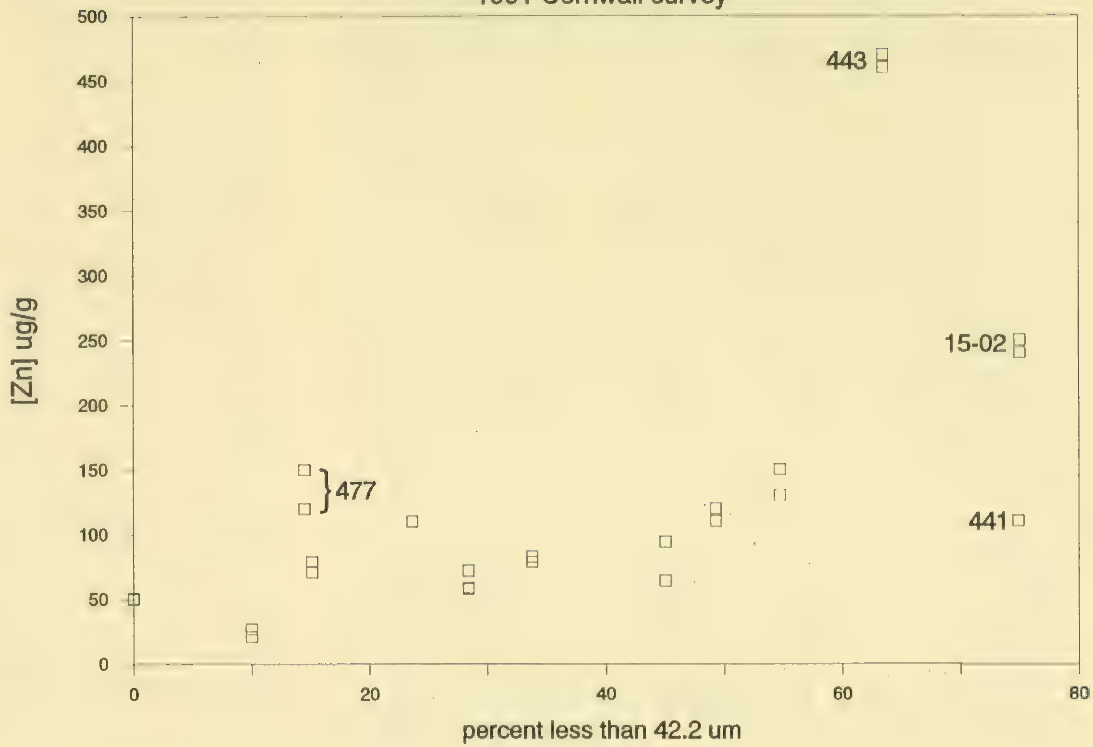


Figure 19

Correlation of sediment zinc levels with grain size

1991 Cornwall survey



zone 3 of the bottom are higher than their pre-colonial value of 65 $\mu g/g$ as a result of the Zn inputs from Courtaulds and other sources. Levels of TKN, total P and TOC in most bottom sediment samples also exceed the LEL.

Contaminant levels observed in this survey can be compared to those of other recent surveys. A collection of suspended solids was undertaken at five river stations representative of this study's Group 1 in 1988 (Anderson and Biberhofer, 1990). Levels of Cu, Pb, As, Cr have decreased somewhat since 1988; levels of other metals are similar in the two surveys. The 1988 survey also showed higher levels of nutrients than observed here; however, only a few results were obtained.

Comparison of bottom sediment levels to those of the 1985 MOE survey (Anderson, 1990) is difficult, because the 1985 data included many stations close to the Ontario shore where considerably elevated contaminant levels were observed. To facilitate comparison, a subset of stations corresponding to the zone 3 observed in this study was utilized. Means of this subset did not differ significantly from those observed in this study, within the standard deviations which were considerable in some parameters. Considering the high-energy nature of the bottom environment, and that the bottom samples appear to be a variable mixture of two grain size populations (as discussed above), the inability to detect a significant difference is not surprising.

Results at station 441 (zone 4) may be compared to station 379 of the 1985 survey, which was in approximately the same location. Levels of As, Cu, Fe, Ni, Pb, and Zn are 50 to 100% higher than those found in 1985, while other metals are similar. Owing to the nature of the sample (mixture of fine and coarse fractions), the significance of even this large difference is questionable. Station 381 (zone 1) also showed higher levels of most metals in 1991 compared to 1985; as station 381 has no fine particulates, this may indicate a real increase in metal contamination of the coarse fraction; however, the source of this contamination would originate from upstream areas in New York State, beyond the study area.

Likewise, comparison of results obtained in this survey with those of March 1991 (Richman, in prep.) is difficult as the 1991 samples were collected at nearshore locations where the greatest impacts from the discharges may be felt. The only mid-channel station in that study where a comparison may be possible was 370A, located near the present station 431. A qualitative comparison with zone 3 bottom sediment results shows that most metal levels are higher in this survey; a notable exception is mercury. On the other hand, her upstream samples 82 and 83 (Lake St. Lawrence) showed higher levels of most metals than those of upstream station 401 in this survey. Due to the mixture of coarse- and fine-grained particles described earlier, no conclusion can be drawn from these differences.

Levels of Suspended Particulate Metal in Water

An estimate of particulate metal concentrations in the water column (μg/L) may be obtained by multiplying the suspended solids concentration (mg/L) in water by the metal concentration in the suspended solids as collected by the sediment traps (ng/g or μg/kg). This assumes that the metal levels in the suspended particles are relatively constant with time, and thus that the sediment trap material (which presents a time-integrated sample of suspended solids chemistry) can represent particulate metal concentrations on any given day. Particulate metal levels were calculated for results of both duplicate sediment traps, and all suspended particulate measurements, and their statistics are enumerated in Appendix E. Note that week 1 and 2 suspended solids data were taken together, as no consistent week-to-week pattern existed for this parameter.

These particulate metal levels were divided by average total metal concentrations in water (obtained via the low-level analysis), to yield percentages of metal carried on particles for each metal and station. The results are given in Table 16. Because of operational difficulties associated with week 2 low-level metals (see section 3.2.3), only week 1 total metal levels were used. If the higher week 2 metal levels are accurate, the results in Table 16 represent overestimates. This may be most serious for zinc, where ratios of week 2 to week 1 total metal concentrations were about four; indeed, particulate levels were often > 100% based on week 1 results. For that reason, particulate fractions were also calculated for week 2 with Zn.

Observed particulate fractions range from about 2% for arsenic and nickel, to greater than 100% for iron. These estimates can be regarded as only rough approximations, as they were taken from separate measurements with several sources of error, as already mentioned in the various discussions. Nevertheless, it is hoped they can be used in calibration of the metals transport model as a guide to the estimated metal particulate levels.

TABLE 16

PARTICULATE METALS AS PERCENTAGE OF TOTAL FROM SUSPENDED SEDIMENT METAL RESULTS

CORNWALL, July 1991

Stn #	Arsenic			Cadmium			Copper			Iron		
	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.
401	0.016	0.745	2.1	0.0043	0.024	17.9	0.095	0.979	9.7	61.9	38.0	162.9
402	0.013	0.798	1.6	0.0046	0.033	13.9	0.119	0.784	15.2	62.1	36.0	172.5
431	0.029	0.757	3.9	0.0076	0.026	29.2	0.389	0.946	41.2	96.2	37.7	255.2
436	0.019	0.705	2.7	0.0054	0.029	18.6	0.215	0.832	25.8	71.5	45.3	157.8
437	0.017	0.743	2.3	0.0056	0.021	26.7	0.184	0.893	20.6	75.2	33.8	222.5
441	0.010	0.628	1.6	0.0034	0.027	12.6	0.078	0.739	10.6	53.9	42.3	127.4
443	0.022	0.833	2.7	0.0059	0.022	26.8	0.159	0.908	17.5	74.6	46.8	159.4
444	0.013	0.763	1.7	0.0049	0.022	22.3	0.170	0.919	18.5	62.7	42.8	146.5
476	0.021	0.665	3.1	0.0059	0.026	22.7	0.177	1.005	17.6	77.9	41.0	190.0
477	0.023	0.755	3.0	0.0055	0.024	22.9	0.178	0.958	18.6	80.9	40.3	200.7
478	0.013	0.850	1.6	0.0043	0.026	16.5	0.107	0.835	12.8	56.4	32.3	174.6
479	0.014	0.878	1.5	0.0048	0.028	17.1	0.120	0.814	14.8	65.5	39.5	165.8

Stn #	Manganese			Nickel			Lead			Zinc				
	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Partic. (ug/L)	Total in water (ug/L)	% Partic.	Wk. 2 tot. in water (ug/L)	% Partic.
401	1.60	5.30	30.2	0.081	4.20	1.9	0.068	0.121	56.4	0.349	0.56	62.3	2.28	15.3
402	1.90	4.98	38.2	0.085	3.93	2.2	0.084	0.122	68.6	0.365	0.16	228.1	1.64	22.3
431	2.48	5.33	46.5	0.141	4.40	3.2	0.166	0.147	112.7	1.924	0.35	549.7	2.43	79.2
436	1.59	5.78	27.5	0.101	4.98	2.0	0.112	0.151	74.2	0.926	1.53	60.5	1.83	50.6
437	2.19	4.88	44.9	0.101	4.75	2.1	0.088	0.133	66.2	0.464	0.11	421.8	1.85	25.1
441	1.65	7.70	21.4	0.069	3.15	2.2	0.065	0.121	53.6	0.343	0.11	311.8	1.51	22.7
443	1.75	6.00	29.2	0.108	4.27	2.5	0.119	0.145	82.1	1.572	4.16	37.8	7.23	21.7
444	2.03	5.15	39.4	0.090	4.45	2.0	0.089	0.129	68.7	0.436	0.09	484.4	2.26	19.3
476	1.73	5.88	29.4	0.108	4.38	2.5	0.110	0.140	78.7	0.494	0.45	109.8	3.08	16.0
477	1.78	5.38	33.1	0.110	4.45	2.5	0.116	0.149	77.7	1.158	1.65	70.2	7.2	16.1
478	1.52	4.85	31.3	0.078	3.75	2.1	0.069	0.138	49.7	0.343	0.11	311.8	2.08	16.5
479	1.91	4.63	41.3	0.086	3.28	2.6	0.074	0.137	53.7	0.428	0.05	856.0	1.71	25.0

Note: All total water concentrations refer to Week 1 results, unless otherwise stated.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Operational difficulties and on-board contamination problems limited the utility of the data obtained in this survey; despite the problems encountered in sample collection, a data set was collected which should be adequate for input into the metals fate and transport model. Data components collected included inputs to the study area, concentrations of conventional parameters and low-level total (unfiltered) metals, and suspended and bottom sediment contaminant data. The following specific conclusions may be drawn:

1. For all metals but zinc, the Domtar/ICI/Cornwall Chemicals combined sewer is the largest point source in the Cornwall-Massena area. It represents 69% of the total point source of cadmium, and 76% of the total point source of mercury. While this survey does not indicate the exact source of these discharges, MISA data indicate the major source of Hg and Cd are from ICI.

2. At the time of the survey, the Courtaulds acid sewer was the largest single point source of zinc. It accounted for approximately 80% of the point source input for this metal. Zinc loadings have decreased significantly since 1980-81; while results of this study reported smaller loadings compared to the MISA monitoring data, the significance of this difference is doubtful due to variability in the loadings results. As Courtaulds ceased operations in late 1992, a five-fold decrease in zinc loadings can be expected.

3. Some evidence also exists for decreased loadings of chromium from Domtar/ICI/ Cornwall Chemicals and mercury from the Cornwall STP, as well as several metals from Courtaulds, compared to 1980-81 data.

4. Present Great Lakes sampling protocol is inadequate to ensure the integrity of field-filtered samples, and is questionable for total metal samples over an extended survey period.

5 Zonation analysis of the conventional water data indicated relative uniformity within the St. Lawrence River, plus water of distinct composition entering from the tributaries on the U.S. side. Within the river, however, a distinctive transport pattern exists for most conventional parameters with higher concentrations found along the north shore as a result of inputs from the Domtar/ICI/Cornwall Chemicals and Courtaulds outfalls.

6. Spatial variation of most low-level metals shows similar features to those shown by conventionals, with the impact of the various discharges being noticeable. Arsenic shows higher levels on the south shore, and cadmium and lead show similar levels on the two shores. East of Cornwall Island, spatial variation of metal levels is irregular.

7. The impact of zinc input from Courtaulds and mercury input from Domtar/ICI/Cornwall Chemicals on sediment quality is confirmed by independent data analyses, as follows: Correlation of bottom sediment zinc and mercury results with grain size distribution shows that stations downstream of these outfalls have higher than expected levels of these metals, but no unusual increases for metals like nickel with only minor inputs. Furthermore, statistical analysis of sediment trap data using the ratio matching/cluster analysis method shows a distinct zone stretching eastward along the north shore, with elevated Hg, Zn, Cu, and Pb levels. As well, the same result is indicated by calibrated hydrodynamic/dispersion modelling (P. Nettleton, in prep.)

8. Bottom sediments in most of the study area are comprised of two fractions: a coarse sandy relatively uncontaminated fraction, and a contaminated silt-clay fraction. These fractions are present in proportions which vary spatially and (probably) temporally, and make time-trend comparisons difficult.

9. In sediment trap samples, most metals are present at levels exceeding the Provincial Sediment Quality Guidelines LEL value; some TKN, Mn and total P levels exceed the SEL. Several bottom sediment metals exceed the LEL, but except for zinc are below the background levels for Great Lakes pre-colonial sediment horizon.

10. Levels of particulate metal in water were calculated from metal concentrations in suspended sediment collected by traps and the suspended solids levels in water. Relative particulate fractions range from about 2% for arsenic and nickel, to greater than 100% for iron. They may be subject to error due to the time-integrated nature of the sediment trap data.

Recommendations

(a) Sampling techniques for future studies.

1. Distilled-deionized water should be obtained sufficiently in advance so that its suitabity as a blank can be checked by metals analysis. It should be packaged in separate daily packages to avoid any contamination by repeated opening and closing of the container. In addition, daily non-system blanks should be taken in order to check for in-line contamination.

2. An on-board "clean" facility using HEPA (high efficiency particulate air) air filtration should be installed on the Guardian for handling of low-level metals samples, including an air lock on the sampling line from outside. This would minimize contamination from external sources.

3. Notwithstanding recommendation 2 above, it may still be preferable to perform filtration at the Dorset clean laboratory facility. At any rate, further testing of methods for field filtration in the "clean" facility is needed.

(b) Potential abatement actions to be considered by the RAP team.

1. Further reduction of mercury and zinc loading from the ICI/Cornwall Chemicals sewer is required to minimize impact of these metals on the sediments and possible toxicity to benthos. Preliminary loading limits, based upon protection of water and sediment from adverse Hg and Zn impacts in the immediate vicinity of these outfalls, are currently under development (P. Nettleton, Cornwall MISA Pilot Site Modelling report, in prep.). Additionally, water quality-based loading limits may be derived from the heavy metals transport modelling currently under development (D. Poulton, in prep.).

2. It may also be desirable to reduce loadings of other metals such as copper, iron, and manganese from Domtar/ICI/Cornwall Chemicals.

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APPENDIX A

Loadings of conventionals and heavy metals

TABLE A-1: LOADINGS OF CONVENTIONALS AND HEAVY METALS DOMTAR/ICI/CORNWALL CHEMICALS SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	143.3	1.2	2	145.4	0.9	2
(a)	Conventionals (kg/d)						
	NH_3-N	8.9	3.6	4	10.9	7.3	4
	TKN	385.	57.	4	405.	117.	4
	(NO_2+NO_3)-N	10.7	4.0	4	7.3	0.1	4
	Total P	40.	8.	4	60.	14.	4
	Suspended Solids	9600.	1800.	4	13400.	1951.	4
	DOC	10600.	1600.	4	11100.	3800.	4
	Total Diss. Solids*	106.	2.9	4	109.	11.	4
	Sodium	24000.	1100.	4	27300.	4900.	4
	Potassium	1870.	340.	4	600.	300.	4
	Calcium	8400.	50.	4	5400.	4500.	4
	Magnesium	1187.	21.	4	808.	653.	4
	Strontium	29.4	0.6	4	32.0	2.2	4
	Barium	9.0	1.1	4	12.0	1.4	4
	Aluminum	197.	28.	4	164.	15.	4
	Fluoride	66.	84.	4	-	-	0
	Chloride	24900.	600.	4	18800.	3200.	4
	Sulfate	25200.	6500.	4	38600.	1600.	4
	Alkalinity	20800.	700.	4	14200.	3000.	4
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	4	ND	-	4
	Cadmium	ND	-	4	229.	71.	4
	Chromium	1360.	190.	4	2510.	330.	4
	Copper	5170.	3400.	4	9260.	8520.	4
	Iron (kg/d)	82.	61.	4	132.	115.	4
	Mercury	32.2	2.5	4	11.6	8.2	4
	Manganese (kg/d)	24.3	4.0	4	38.1	3.0	4
	Nickel	1140.	600.	4	2900.	1230.	4
	Lead	2300.	1000.	4	3500.	3100.	4
	Zinc	4400.	760.	4	6900.	2500.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-2: LOADINGS OF CONVENTIONALS AND HEAVY METALS COURTAULDS ACID SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	5.06	.17	2	4.77	.28	2
(a)	Conventionals (kg/d)						
	NH_3-N	0.45	.025	4	.024	.0.1	4
	TKN	4.19	2.67	4	4.15	0.49	4
	(NO_2+NO_3)-N	0.88	0.15	4	0.59	0.11	4
	Total P	0.37	0.33	4	1.00	0.13	4
	Suspended Solids	999.	386.	4	768.	517.	4
	DOC	808.	169.	4	696.	81.	4
	Total Diss. Solids*	27.4	7.3	4	24.3	0.8	4
	Sodium	7200.	1500.	4	6200.	400.	4
	Potassium	12.6	1.1	4	12.5	1.7	4
	Calcium	50.2	9.6	4	91.7	10.2	4
	Magnesium	17.5	2.3	4	18.5	2.3	4
	Strontium	0.41	0.01	4	0.42	0.05	4
	Barium	0.076	0.004	4	0.132	0.093	4
	Aluminum	0.74	0.20	4	0.95	0.54	4
	Fluoride	0.75	0.27	4	0.48	0.50	4
	Chloride	1130.	170.	4	1150.	140.	4
	Sulfate	17500.	4200.	4	14900.	1190.	4
	Alkalinity	-	-	0	-	-	0
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	4	ND	-	4
	Cadmium	ND	-	4	5.0	3.2	4
	Chromium	198.	55.	4	207.	15.	4
	Copper	108.	37.	4	178.	111.	4
	Iron (kg/d)	7.5	0.8	4	12.0	2.5	4
	Mercury	3.0	0.2	4	4.3	2.8	4
	Manganese	1640.	340.	4	1550.	130.	4
	Nickel	220.	66.	4	187.	15.	4
	Lead	400.	50.	4	720.	260.	4
	Zinc **(kg/d)**	191.	55.	4	175.	46.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-3: LOADINGS OF CONVENTIONALS AND HEAVY METALS COURTAULDS VISCOSE SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	1.37	0.08	2	1.08	0.09	2
(a)	Conventionals (kg/d)						
	NH_3-N	0.068	0.003	4	0.054	0.004	4
	TKN	0.904	0.036	4	0.705	0.046	4
	(NO_2+NO_3)-N	0.068	0.003	4	0.054	0.004	4
	Total P	0.093	0.033	4	0.075	0.008	4
	Suspended Solids	182.	16.	4	96.	18.	4
	DOC	64.5	21.7	4	54.7	7.8	4
	Total Diss. Solids*	1.70	0.55	4	1.32	0.18	4
	Sodium	467.	187.	4	408.	92.	4
	Potassium	1.96	0.17	4	1.87	0.46	4
	Calcium	7.77	0.48	4	6.43	1.95	4
	Magnesium	1.49	0.76	4	0.85	0.07	4
	Strontium	0.165	0.071	4	0.084	0.012	4
	Barium	0.024	0.014	4	0.010	0.003	4
	Aluminum	0.200	0.190	4	0.106	0.077	4
	Fluoride	0.169	0.062	4	0.108	0.007	4
	Chloride	379.	105.	4	320.	61.	4
	Sulfate	256.	184.	4	119.	24.	4
	Alkalinity	583.	108.	4	464.	74.	4
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	4	ND	-	4
	Cadmium	ND	-	4	0.6	0.3	4
	Chromium	23.9	11.2	4	16.8	2.1	4
	Copper	28.4	20.7	4	6.8	1.1	4
	Iron (kg/d)	0.60	0.44	4	0.20	0.09	4
	Mercury	2.12	2.55	4	1.11	0.72	4
	Manganese	42.6	30.9	4	18.9	4.8	4
	Nickel	18.3	6.6	4	11.1	7.2	4
	Lead	106.	67.	4	47.	16.	4
	Zinc	2750.	2660.	4	540.	330.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-4: LOADINGS OF CONVENTIONALS AND HEAVY METALS COURTAULDS COMBINED STORM SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	13.4	1.2	2	14.3	6.0	2
(a)	Conventionals (kg/d)						
	NH_3-N	1.21	0.73	4	1.45	0.38	4
	TKN	3.9	0.8	4	7.2	1.9	4
	(NO_2+NO_3)-N	0.83	0.29	4	0.71	0.24	4
	Total P	0.61	0.17	4	0.67	0.08	4
	Suspended Solids	63.	10.	4	86.	19.	4
	DOC	35.	4.	4	48.	25.	4
	Total Diss. Solids*	3.39	0.18	4	4.55	1.30	4
	Sodium	398.	13.	4	706.	148.	4
	Potassium	19.7	3.0	4	22.4	8.7	4
	Calcium	515.	34.	4	538.	192.	4
	Magnesium	105.	6.	4	115.	42.	4
	Strontium	1.21	0.48	4	1.49	0.45	4
	Barium	0.282	0.031	4	0.328	0.122	4
	Aluminum	1.48	0.45	4	1.31	0.55	4
	Fluoride	2.15	0.15	4	2.19	0.68	4
	Chloride	346.	31.	4	388.	116.	4
	Sulfate	910.	10.	4	1620.	430.	4
	Alkalinity	1170.	80.	4	1040.	260.	4
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	4	ND	-	4
	Cadmium	ND	-	4	13.	11.	4
	Chromium	217.	57.	4	304.	129.	4
	Copper	131.	71.	4	70.	20.	4
	Iron (kg/d)	3.55	1.41	4	5.37	0.86	4
	Mercury	ND	-	4	0.8	1.1	4
	Manganese	146.	27.	4	203.	54.	4
	Nickel	56.	46.	4	131.	41.	4
	Lead	ND	-	4	107.	57.	4
	Zinc **(kg/d)**	4.11	0.08	4	11.3	3.3	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-5: LOADINGS OF CONVENTIONALS AND HEAVY METALS COURTAULDS TANK CAR UNLOADING SEWER, JULY, 1991.

	July 17-19			July 22-24		
	Mean	SD	N	Mean	SD	N
Flow ($10^3 m^3/d$)	5.70	0.05	2	5.69	0.31	2
(a) Conventionals (kg/d)						
NH_3-N	0.93	0.49	4	0.79	0.16	4
TKN	3.20	1.03	4	4.08	1.34	4
(NO_2+NO_3)-N	0.285	0.002	4	0.285	0.012	4
Total P	2.46	2.35	4	0.67	0.43	4
Suspended Solids	432.	508.	4	645.	356.	4
DOC	16.4	1.5	4	14.4	1.7	4
Total Diss. Solids*	2.3	1.0	4	3.2	1.3	4
Sodium	154.	35.	4	146.	31.	4
Potassium	9.5	1.6	4	9.7	1.6	4
Calcium	570.	450.	4	910.	476.	4
Magnesium	46.5	4.8	4	48.0	5.0	4
Strontium	1.21	0.48	4	1.49	0.45	4
Barium	0.141	0.038	4	0.159	0.034	4
Aluminum	1.90	2.21	4	2.39	1.31	4
Fluoride	0.91	0.01	4	1.50	0.72	4
Chloride	131.3	6.8	4	126.7	3.7	4
Sulfate	1400.	1150.	4	2220.	1250.	4
Alkalinity	313.	37.	4	332.	35.	4
(b) Heavy Metals (g/d)						
Arsenic	ND	-	4	ND	-	4
Cadmium	ND	-	4	8.	2.	4
Chromium	200.	226.	4	86.	19.	4
Copper	144.	160.	4	190.	312.	4
Iron (kg/d)	18.8	10.7	4	6.4	1.6	4
Mercury	ND	-	4	ND	-	4
Manganese	143.	37.	4	136.	52.	4
Nickel	391.	620.	4	47.	10.	4
Lead	68.	30.	4	67.	15.	4
Zinc	3800.	1000.	4	3400.	1600.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-6: LOADINGS OF CONVENTIONALS AND HEAVY METALS COURTAULDS ACID RECOVERY SEWER, JULY, 1991.

	July 17-19			July 22-24		
	Mean	SD	N	Mean	SD	N
Flow ($10^3 m^3/d$)	26.3	1.2	2	28.4	1.0	2
(a) Conventionals (kg/d)						
NH_3-N	2.63	0.10	4	1.41	0.04	4
TKN	6.90	0.53	4	10.21	0.92	4
(NO_2+NO_3)-N	3.59	1.13	4	2.09	0.75	4
Total P	0.526	0.020	4	0.707	0.298	4
Suspended Solids	123.	13.	4	129.	27.	4
DOC	60.5	3.2	4	65.4	1.3	4
Total Diss. Solids*	6.73	0.39	4	8.97	2.41	4
Sodium	780.	70.	4	1490.	840.	4
Potassium	41.1	3.2	4	41.5	1.1	4
Calcium	1010.	50.	4	1020.	20.	4
Magnesium	207.	7.	4	225.	9.	4
Strontium	4.21	0.16	4	4.64	0.03	4
Barium	0.55	0.02	4	0.64	0.02	4
Aluminum	2.48	1.68	4	2.64	0.45	4
Fluoride	26.3	1.0	4	28.1	0.9	4
Chloride	622.	29.	4	682.	28.	4
Sulfate	2120.	190.	4	3300.	1800.	4
Alkalinity	2000.	4.	4	2300.	200.	4
(b) Heavy Metals (g/d)						
Arsenic	ND	-	4	ND	-	4
Cadmium	ND	-	4	17.	12.	4
Chromium	277.	54.	4	652.	452.	4
Copper	191.	58.	4	82.	22.	4
Iron (kg/d)	6.93	5.31	4	4.22	1.08	4
Mercury	ND	-	4	ND	-	4
Manganese	242.	62.	4	234.	43.	4
Nickel	211.	128.	4	168.	53.	4
Lead	237.	122.	4	224.	97.	4
Zinc **(kg/d)**	18.3	1.7	4	15.2	5.8	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-7: LOADINGS OF CONVENTIONALS AND HEAVY METALS CARAVELLE CARPETS SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	6.55	0.24	2	7.01	0.33	4
(a)	Conventionals (kg/d)						
	NH_3-N	0.66	0.02	4	0.53	0.22	4
	TKN	1.89	0.20	4	2.72	0.25	4
	(NO_2+NO_3)-N	0.65	0.36	4	0.53	0.20	4
	Total P	0.131	0.004	4	0.140	0.005	4
	Suspended Solids	31.6	8.4	4	29.1	2.0	4
	DOC	60.5	3.1	4	65.4	1.3	4
	Total Diss. Solids*	1.64	0.11	4	1.87	0.07	4
	Sodium	178.	26.	4	230.	15.	4
	Potassium	10.4	0.6	4	11.1	0.3	4
	Calcium	254.	8.	4	259.	8.	4
	Magnesium	207.	7.	4	225.	9.	4
	Strontium	1.08	0.05	4	1.19	0.05	4
	Barium	0.143	0.009	4	0.163	0.005	4
	Aluminum	0.444	0.046	4	0.478	0.161	4
	Fluoride	0.786	0.023	4	0.909	0.046	4
	Chloride	157.	7.	4	168.	8.	4
	Sulfate	527.	80.	4	663.	29.	4
	Alkalinity	476.	11.	4	472.	13.	4
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	4	ND	-	4
	Cadmium	ND	-	4	6.	2.	4
	Chromium	72.	8.	4	91.	21.	4
	Copper	38.	10.	4	31.	18.	4
	Iron (kg/d)	0.98	0.16	4	1.05	0.12	4
	Mercury	ND	-	4	ND	-	4
	Manganese	61.	4.	4	77.	4.	4
	Nickel	26.	21.	4	42.	25.	4
	Lead	67.	25.	4	86.	36.	4
	Zinc	4300.	800.	4	5700.	400.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-8: LOADINGS OF CONVENTIONALS AND HEAVY METALS REYNOLDS MAIN SEWER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	1.97	-	1	1.97	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	2.36	0.	2	2.96	0	2
	TKN	5.12	0.	2	5.96	0.35	2
	(NO_2+NO_3)-N	0.25	0.07	2	0.15	0.07	2
	Total P	0.83	0.	2	0.41	0.03	2
	Suspended Solids	22.5	0.1	2	14.7	1.5	2
	DOC	29.7	0.3	2	30.4	2.6	2
	Total Diss. Solids*	11.7	10.	2	13.6	0.	2
	Sodium	4370.	120.	2	5400.	190.	2
	Potassium	7.72	0.31	2	9.24	0.17	2
	Calcium	33.9	0.3	4	30.9	0	2
	Magnesium	12.5	.1	2	11.9	.2	2
	Strontium	0.285	0.014	2	0.266	0.014	2
	Barium	0.033	0.001	2	0.036	0.003	2
	Aluminum	3.74	0.	2	2.27	0.14	2
	Fluoride	55.2	0.	2	37.6	0.3	2
	Chloride	141.8	1.1	2	159.3	0.4	2
	Sulfate	8760.	70.	2	10500.	800.	2
	Alkalinity	979.	9.	2	693.	8.	2
(b)	Heavy Metals (g/d)						
	Arsenic	23.	1.	2	12.	0.	2
	Cadmium	ND	-	1	ND	-	2
	Chromium	25.	1.	2	22.	0.	2
	Copper	82.	2.	2	30.	3.	2
	Iron (kg/d)	0.27	.07	2	0.16	0.02	2
	Mercury	ND	-	2	nd	-	2
	Manganese	11.8	0.8	2	7.5	0.3	2
	Nickel	32.5	0.1	2	36.4	4.2	2
	Lead	14.8	7.0	2	25.6	11.1	2
	Zinc	621.	98.	2	345.	14.	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-9: LOADINGS OF CONVENTIONALS AND HEAVY METALS REYNOLDS SECOND SEWER (SUBMERGED), JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	10.2	-	1	10.2	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	0.51	0.	2	0.51	0	2
	TKN	2.29	0.36	2	3.31	0.36	2
	(NO_2+NO_3)-N	1.78	0.36	2	2.29	0.36	2
	Total P	4.17	0.	2	3.16	0.14	2
	Suspended Solids	54.	14.	2	126.	76.	2
	DOC	26.5	1.4	2	22.4	0.	2
	Total Diss. Solids*	3.21	0.06	2	2.23	0.02	2
	Sodium	389.	16.	2	168.	3.	2
	Potassium	21.9	0.14	2	23.1	1.0	2
	Calcium	442.	3.	2	379.	0.	2
	Magnesium	96.2	1.4	2	85.5	0.	2
	Strontium	2.14	0.	2	2.04	0.	2
	Barium	0.33	0.01	2	0.38	0.04	2
	Aluminum	1.98	0.22	2	3.10	0.79	2
	Fluoride	2.65	0.29	2	3.67	0.29	2
	Chloride	761.	23.	2	278.	4.	2
	Sulfate	301.	1.	2	314.	4.	2
	Alkalinity	983.	13.	2	972.	1.	2
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	2	ND	-	2
	Cadmium	ND	-	2	ND	-	2
	Chromium	137.	7.	2	122.	14.	2
	Copper	300.	7.	2	117.	7.	2
	Iron (kg/d)	1.47	0.07	2	4.22	1.22	2
	Mercury	ND	-	2	nd	-	2
	Manganese	540.	0.	2	1080.	200.	2
	Nickel	51.	0.	2	41.	14.	2
	Lead	ND	-	2	158.	65.	2
	Zinc	4020.	72.	2	3210.	360.	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-10: LOADINGS OF CONVENTIONALS AND HEAVY METALS GENERAL MOTORS MAIN SURFACE DISCHARGE, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	0.74	-	1	1.18	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	0.111	0.	2	0.059	0.	2
	TKN	0.259	0.	2	0.414	0.	2
	(NO_2+NO_3)-N	0.037	0	2	0.059	0.	2
	Total P	0.030	0.	2	0.036	0.017	2
	Suspended Solids	1.30	0.16	2	1.65	0.17	2
	DOC	1.96	0.05	2	3.37	0.08	2
	Total Diss. Solids*	0.470	0.001	2	0.754	0.001	2
	Sodium	83.4	0.4	2	141.5	8.3	2
	Potassium	10.7	0.1	2	15.8	0.3	2
	Calcium	37.7	0.2	2	57.4	0.3	2
	Magnesium	10.2	0.1	2	15.6	0.2	2
	Strontium	0.285	0.005	2	0.426	0.017	2
	Barium	0.007	0.	2	0.014	0.	2
	Aluminum	0.059	0.007	2	0.106	0.034	2
	Fluoride	0.326	0.	2	0.544	0.033	2
	Chloride	157.	1.	2	230.	27.	2
	Sulfate	64.2	1.4	2	101.4	0.5	2
	Alkalinity	42.7	0.	2	85.8	0.3	2
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	2	ND	-	2
	Cadmium	ND	-	2	0.1	0.	2
	Chromium	10.0	0.5	2	17.1	2.5	2
	Copper	17.0	1.0	2	4.7	0.6	2
	Iron (kg/d)	0.281	0.126	2	0.057	0.001	2
	Mercury	ND	-	2	ND	-	2
	Manganese	40.3	1.6	2	56.1	0.8	2
	Nickel	18.9	0.5	2	33.7	2.5	2
	Lead	ND	-	2	18.9	5.0	2
	Zinc	22.6	2.6	2	23.6	1.7	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-11: LOADINGS OF CONVENTIONALS AND HEAVY METALS CORNWALL STP, JULY, 1991.

	July 17-19			July 22-24		
	Mean	SD	N	Mean	SD	N
Flow ($10^3 m^3/d$)	39.6	-	1	42.0	1.0	2
(a) Conventionals (kg/d)						
NH_3-N	284.	4.	2	331.	38.	4
TKN	362.	6.	2	406.	52.	4
(NO_2+NO_3)-N	7.9	0.	2	5.2	3.5	4
Total P	9.5	0.	2	11.4	2.2	4
Suspended Solids	331.	87.	2	350.	12.	4
DOC	410.	3.	2	381.	28.	4
Total Diss. Solids*	19.9	0.1	2	21.0	1.8	4
Sodium	2500.	20.	2	2490.	130.	4
Potassium	286.	2.	2	285.	37.	4
Calcium	2500.	20.	2	2700.	300.	4
Magnesium	550.	6.	2	587.	65.	4
Strontium	30.4	0.	2	34.4	4.4	4
Barium	1.19	0.06	2	1.39	0.11	4
Aluminum	23.8	4.5	2	27.7	4.3	4
Fluoride	26.1	1.1	2	36.4	9.6	4
Chloride	3040.	3.	2	3150.	280.	4
Sulfate	2480.	960.	2	3880.	450.	4
Alkalinity	7300.	10.	2	7500.	600.	4
(b) Heavy Metals (g/d)						
Arsenic	ND	-	2	ND	-	4
Cadmium	16.	11.	2	57.	11.	4
Chromium	356.	56.	2	620.	11.	4
Copper	236.	92.	2	225.	5.	4
Iron (kg/d)	7.3	0.8	2	8.7	1.4	4
Mercury	ND	-	2	ND	-	4
Manganese	2340.	0.	2	2450.	1.4	4
Nickel	277.	56.	2	451.	89.	4
Lead	653.	196.	2	653.	220.	4
Zinc	613.	84.	2	1080.	330.	4

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-12: LOADINGS OF CONVENTIONALS AND HEAVY METALS GRASSE RIVER, JULY 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	250.	-	1	250.	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	57.	2.	2	56.	22.	2
	TKN	431.	69.	2	278.	10.	2
	(NO_2+NO_3)-N	77.	0.	2	83.	15.	2
	Total P	50.	0.	4	38.	0.5	2
	Suspended Solids	2120.	50.	4	1910.	50.	4
	DOC	2850.	100.	4	2500.	0.	4
	Total Diss. Solids*	101.	1.	2	107.	1.	2
	Sodium	6100.	200.	2	6800.	20.	2
	Potassium	820.	10.	2	910.	30.	2
	Calcium	18300.	200.	2	20800.	200.	2
	Magnesium	4640.	10.	2	4960.	50.	2
	Strontium	76.	0.	2	83.	0.	2
	Barium	12.2	0.5	2	11.8	0.	2
	Aluminum	27.8	9.8	2	27.8	0.	2
	Fluoride	250.	0.	2	250.	0.	2
	Chloride	10100.	100.	2	11300.	100.	2
	Sulfate	13400.	400.	2	14000.	100.	2
	Alkalinity	49600.	300.	2	51700.	300.	2
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	2	ND	-	2
	Cadmium	ND	-	2	ND	-	2
	Chromium	ND	-	2	ND	-	2
	Copper	700.	0.	2	700.	0.	2
	Iron (kg/d)	125.	9.	2	167.	0.	2
	Mercury	ND	-	2	ND	-	2
	Manganese (kg/d)	27.5	0.5	2	24.0	0.5	2
	Nickel	2100.	0.	2	ND	-	2
	Lead	ND	-	2	ND	-	2
	Zinc	695.	0.	2	1040.	1.	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-13: LOADINGS OF CONVENTIONALS AND HEAVY METALS RAQUETTE RIVER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	2640.	-	1	2810.	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	42.	7.	2	67.	-	1
	TKN	687.	0.	2	760.	-	1
	(NO_2+NO_3)-N	522.	9.	2	422.	-	1
	Total P	30.3	1.9	2	30.9	-	1
	Suspended Solids	6500.	600.	2	12100.	-	1
	DOC	8900.	0.	2	10900.	-	1
	Total Diss. Solids*	203.	12.	2	124.	-	1
	Sodium	12000.	700.	2	7900.	400.	2
	Potassium	1960.	20.	2	1530.	60.	2
	Calcium	37200.	3000.	2	20700.	1000.	2
	Magnesium	8530.	490.	2	6330.	200.	2
	Strontium	76.	0.	2	83.	0.	2
	Barium	38.	2.	2	34.	0.	2
	Aluminum	145.	56.	2	197.	0.	2
	Fluoride	211.	0.	2	169.	0.	2
	Chloride	19300.	1900.	2	10700.	800.	2
	Sulfate	33000.	2900.	2	21000.	400.	2
	Alkalinity	91000.	5400.	2	55200.	3200.	2
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	2	ND	-	2
	Cadmium	ND	-	2	1100.	1.	2
	Chromium	ND	-	2	ND	-	2
	Copper	1900.	1.	2	2800.	0.	2
	Iron (kg/d)	396.	37.	2	915.	60.	2
	Mercury	ND	-	2	ND	-	2
	Manganese (kg/d)	55.5	3.7	2	81.6	4.0	2
	Nickel	ND	-	2	ND	-	2
	Lead	ND	-	2	8400.	0.	2
	Zinc	2600.	0.	2	4200.	2000.	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

TABLE A-14: LOADINGS OF CONVENTIONALS AND HEAVY METALS ST. REGIS RIVER, JULY, 1991.

		July 17-19			July 22-24		
		Mean	SD	N	Mean	SD	N
	Flow ($10^3 m^3/d$)	678.	-	1	580.	-	1
(a)	Conventionals (kg/d)						
	NH_3-N	12.2	0.	2	18.0	2.5	2
	TKN	386.	48.	2	189.	4.	2
	(NO_2+NO_3)-N	33.9	0.	2	26.1	0.	2
	Total P	23.0	1.0	2	16.8	0.	2
	Suspended Solids	1490.	0.	2	2000.	290.	2
	DOC	2800.	140.	2	2300.	80.	2
	Total Diss. Solids*	68.5	0.3	2	69.6	0.3	2
	Sodium	3740.	0.	2	3980.	110.	2
	Potassium	593.	5.	2	566.	4.	2
	Calcium	14200.	200.	2	13300.	200.	2
	Magnesium	3460.	0.	2	3390.	120.	2
	Strontium	45.8	2.4	2	51.3	0.4	2
	Barium	9.8	0.5	2	9.6	0.4	2
	Aluminum	27.1	9.6	2	55.1	12.3	2
	Fluoride	678.	0.	2	580.	0.	2
	Chloride	5800.	50.	2	6440.	80.	2
	Sulfate	7900.	100.	2	8100.	70.	2
	Alkalinity	36100.	100.	2	36000.	100.	2
(b)	Heavy Metals (g/d)						
	Arsenic	ND	-	2	ND	-	2
	Cadmium	ND	-	2	ND	-	2
	Chromium	ND	-	2	ND	-	2
	Copper	510.	240.	2	580.	0.	2
	Iron (kg/d)	153.	5.	2	136.	4.	2
	Mercury	ND	-	2	ND	-	2
	Manganese (kg/d)	15.6	1.0	2	17.1	1.2	2
	Nickel	ND	-	2	ND	-	2
	Lead	ND	-	2	ND	-	2
	Zinc	680.	0.	2	ND	-	2

NOTE*: Computed from conductivity * 0.65. Values in 10^3 kg/day.

APPENDIX B

SUMMARY OF RELEVANT MISA MONITORING REGULATION LOADING DATA

METAL LOADINGS AS MEASURED DURING THE MISA MONITORING REGULATION (kg/day)

AS REPORTED IN THE VARIOUS MISA MONITORING REPORTS

Parameter	Courtaulds						Domtar	ICI	Cornwall Chemicals	Cornwall WPCP	Total Loading
	Acid Sewer	Alkaline Sewer	Combined Storm	Acid Recovery	Tankcar Unloading	Caravelle					
(kg/day)											
Al	1.970	0.295	1.579	2.906	0.679	0.987	204.839	0.634	0.225	127.5	341.61
Cd	0.015	0.002	0.012	0.040	0.008	0.013		0.032	0.001	0	0.12
Cr	0.612	0.006	0.160	0.181	0.029	0.087		0.079	0.003	0.44	1.60
Cu	0.307	0.039	0.156	0.772	0.055	0.074	1.613	0.082	0.01	0.44	3.55
Pb	1.257	0.155	0.113	0.394	0.073	0.147		0.178		0.87	3.19
Ni	0.156	0.022	0.079	0.241	0.038	0.088		0.037	0.088	0.44	1.19
Zn	273.601	2.932	5.074	37.717	10.144	15.923	5.795	0.111	0.08	1.31	352.69
Hg	0.056	0.007	0.002	0.006	0.001	0.002		0.063	0.002	0.002	0.078

APPENDIX C

Concentration of heavy metals in St. Lawrence River

as measured by ultra-trace methods

TABLE C.1

CONCENTRATIONS OF HEAVY METALS IN ST. LAWRENCE RIVER (µg/L)
AS MEASURED BY ULTRA-TRACE METHODS

Cornwall, July 1991

(a) Arsenic

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	0.745	0.087	0.65	0.86	4	0.908	0.067	0.72	0.96
402	4	0.798	0.058	0.72	0.86	4	0.663	0.045	0.58	0.70
431	3	0.757	0.135	0.62	0.89	4	0.935	0.055	0.88	1.00
436	4	0.705	0.130	0.51	0.78	4	0.945	0.144	0.76	1.10
437	4	0.743	0.063	0.67	0.82	4	0.715	0.131	0.55	0.83
441	4	0.628	0.048	0.59	0.69	6	0.782	0.202	0.53	0.97
443	4	0.833	0.045	0.77	0.87	4	0.730	0.065	0.65	0.80
444	4	0.763	0.061	0.70	0.82	4	0.665	0.191	0.48	0.93
476	4	0.665	0.148	0.50	0.83	4	0.833	0.055	0.76	0.88
477	4	0.755	0.031	0.73	0.80	4	0.933	0.045	0.88	0.99
478	4	0.850	0.074	0.79	0.94	4	0.995	0.150	0.85	1.20
479	4	0.878	0.101	0.79	1.00	4	0.978	0.173	0.78	1.20

(b) Cadmium

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	0.024	0.003	0.020	0.028	4	0.017	0.002	0.014	0.019
402	4	0.033	0.001	0.031	0.034	6	0.030	0.005	0.028	0.035
431	4	0.026	0.003	0.023	0.029	3	0.022	0.001	0.021	0.023
436	4	0.029	0.005	0.024	0.034	4	0.025	0.003	0.023	0.029
437	4	0.021	0.004	0.016	0.025	3	0.018	0.003	0.016	0.021
441	4	0.027	0.008	0.016	0.034	6	0.026	0.005	0.019	0.032
443	4	0.022	0.003	0.018	0.024	4	0.020	0.002	0.018	0.023
444	4	0.022	0.003	0.019	0.025	4	0.018	0.001	0.016	0.019
476	4	0.026	0.003	0.023	0.029	3	0.022	0.002	0.020	0.024
477	4	0.024	0.003	0.021	0.027	4	0.022	0.002	0.019	0.024
478	4	0.026	0.004	0.022	0.031	4	0.023	0.002	0.021	0.026
479	4	0.028	0.002	0.026	0.031	4	0.025	0.002	0.023	0.027

(c) Copper

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	0.979	0.022	0.957	1.009	4	0.858	0.075	0.752	0.923
402	4	0.784	0.058	0.703	0.831	6	0.959	0.032	0.934	1.012
431	4	0.946	0.013	0.930	0.961	4	1.123	0.191	1.002	1.407
436	4	0.832	0.068	0.753	0.920	4	1.039	0.064	0.977	1.115
437	4	0.893	0.046	0.835	0.945	3	0.811	0.289	0.477	0.983
441	3	0.739	0.030	0.706	0.764	6	0.765	0.150	0.471	0.891
443	4	0.908	0.031	0.867	0.936	4	0.923	0.058	0.846	0.980
444	4	0.919	0.018	0.904	0.940	4	0.963	0.160	0.855	1.198
476	4	1.005	0.028	0.976	1.034	4	1.030	0.050	0.982	1.094
477	3	0.958	0.072	0.891	1.034	4	1.208	0.170	0.963	1.352
478	4	0.835	0.031	0.798	0.865	4	0.925	0.044	0.871	0.970
479	4	0.814	0.040	0.755	0.843	4	0.927	0.063	0.865	1.014

(d) Iron

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	3	38.0	0.0	38.0	38.0	4	38.0	1.4	37.0	40.0
402	4	36.0	2.9	32.0	39.0	6	46.3	4.2	43.0	52.0
431	3	37.7	4.7	34.0	43.0	4	49.0	2.6	46.0	52.0
436	4	45.3	5.8	39.0	53.0	4	49.0	6.3	42.0	57.0
437	4	33.8	6.2	27.0	42.0	4	37.0	2.3	35.0	39.0
441	4	42.3	5.1	35.0	47.0	6	42.5	5.9	34.0	48.0
443	4	46.8	8.7	34.0	53.0	4	41.8	4.0	37.0	46.0
444	4	42.8	3.0	40.0	47.0	4	38.5	4.4	33.0	42.0
476	4	41.0	9.1	33.0	54.0	4	46.3	3.8	41.0	50.0
477	4	40.3	1.5	38.0	41.0	4	47.8	2.2	45.0	50.0
478	4	32.3	6.1	27.0	41.0	4	40.8	10.4	33.0	55.0
479	4	39.5	0.6	39.0	40.0	4	47.8	1.5	47.0	50.0

(e) Manganese

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	3	5.30	0.10	5.2	5.4	4	5.10	0.28	4.7	5.3
402	4	4.98	0.25	4.7	5.3	6	5.98	0.19	5.8	6.3
431	4	5.33	0.15	5.2	5.5	4	5.95	0.17	5.8	6.2
436	4	5.78	0.33	5.4	6.2	4	5.73	0.31	5.3	6.0
437	4	4.88	0.26	4.6	5.1	4	4.58	0.10	4.5	4.7
441	4	7.70	0.86	7.3	8.9	6	6.50	0.57	5.6	7.2
443	4	6.00	0.22	5.7	6.1	4	6.50	0.53	6.2	7.2
444	4	5.15	0.34	4.8	5.6	4	5.28	0.32	5.0	5.6
476	4	5.88	0.21	5.6	6.1	4	6.30	0.43	5.7	6.7
477	4	5.38	0.13	5.2	5.5	4	6.15	0.37	5.9	6.7
478	4	4.85	0.24	4.6	5.1	4	5.23	0.60	4.8	6.1
479	4	4.63	0.13	4.5	4.8	4	7.10	0.53	6.5	7.6

(f) Nickel

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	4.20	0.14	4.1	4.4	4	4.63	0.17	4.4	4.8
402	4	3.93	0.78	3.3	4.6	4	4.77	0.10	3.2	4.9
431	3	4.4	0.0	4.4	4.4	4	4.68	0.05	4.6	4.7
436	4	4.98	0.05	4.9	5.0	4	4.63	0.22	4.5	5.0
437	4	4.75	0.24	4.6	5.1	4	4.73	0.05	4.7	4.8
441	4	3.15	0.06	3.1	3.2	6	4.58	0.10	4.5	4.7
443	3	4.27	0.15	4.1	4.4	4	4.60	0.08	4.5	4.7
444	4	4.45	0.29	4.2	4.7	4	4.73	0.09	4.6	4.8
476	4	4.38	0.05	4.3	4.4	4	4.58	0.05	4.5	4.6
477	4	4.45	0.13	4.3	4.6	4	4.73	0.05	4.7	4.8
478	4	3.75	0.06	3.7	3.8	4	4.68	0.05	4.6	4.7
479	4	3.28	0.10	3.2	3.4	4	4.43	0.05	4.4	4.5

(g) Lead

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	0.121	0.009	0.112	0.133	4	0.147	0.018	0.132	0.165
402	4	0.122	0.005	0.116	0.129	6	0.146	0.035	0.101	0.195
431	4	0.147	0.009	0.140	0.160	4	0.145	0.009	0.133	0.153
436	4	0.151	0.033	0.122	0.197	3	0.149	0.029	0.123	0.180
437	4	0.133	0.013	0.117	0.148	3	0.272	0.014	0.256	0.277
441	3	0.121	0.005	0.115	0.125	6	0.127	0.021	0.099	0.162
443	4	0.145	0.014	0.127	0.171	4	0.192	0.039	0.160	0.248
444	4	0.129	0.014	0.124	0.149	4	0.268	0.088	0.138	0.324
476	4	0.140	0.007	0.131	0.146	4	0.153	0.007	0.146	0.161
477	4	0.149	0.009	0.141	0.163	3	0.258	0.082	0.166	0.324
478	4	0.138	0.005	0.133	0.143	4	0.257	0.044	0.198	0.301
479	4	0.137	0.012	0.129	0.155	4	0.169	0.046	0.105	0.208

(h) Zinc

	Week 1					Week 2				
Stn #	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
401	4	0.56	0.21	0.36	0.83	4	2.28	0.31	2.01	2.70
402	4	0.16	0.05	0.12	0.22	5	1.64	0.21	1.33	1.88
431	4	0.35	0.08	0.28	0.47	4	2.43	0.71	1.41	3.02
436	3	1.53	0.02	1.51	1.54	4	1.83	0.21	1.55	2.02
437	4	0.11	0.02	0.09	0.14	4	1.85	0.21	1.55	2.02
441	4	0.11	0.07	0.06	0.20	6	1.51	0.11	1.38	1.68
443	3	4.16	0.33	3.89	4.53	4	7.23	0.34	6.92	7.61
444	4	0.09	0.03	0.06	0.11	4	2.26	0.26	2.04	2.64
476	4	0.45	0.16	0.25	0.62	4	3.08	0.11	2.94	3.20
477	4	1.65	0.29	1.26	1.91	4	7.20	0.55	6.66	7.84
478	3	0.11	0.05	0.06	0.15	4	2.08	0.68	1.49	2.87
479	3	0.05	0.04	0.02	0.10	4	1.71	0.08	1.64	1.82

APPENDIX D

Sediment quality data

TABLE D.1

NUTRIENT AND CONVENTIONALS CONCENTRATIONS IN SEDIMENTS
CORNWALL LOW-LEVEL METALS SURVEY, JULY 1991

(a) Sediment trap samples

BOW	STN TYPE	STN #	DATE YYMMDD	TIME	SAMPLE DEPTH (m.)	SMP TYPE	FIELD SAMPLE NUMBER	NNTKUR MG/G D as N RMK	PPUT MG/G D as P RMK	RSTLOI MG/G D RMK	TOC MG/G D as C RMK	ALUT UG/G D as Al RMK	CAUT UG/G D as Ca RMK	MGUT UG/G D as Mg RMK
12	2	401	910729	0	5.4	51	10537	4.30	1.30	75.0	34.00	15000.00	37800.00	12800.00
12	2	401	910729	0	5.4	51	10538	4.40	1.40	74.0	35.00	15000.00	37100.00	12700.00
12	2	402	910730	0	3.8	51	10525	5.40	1.60	100.0	44.00	18000.00	49600.01	13000.00
12	2	402	910730	0	3.8	51	10526	5.60	1.80	100.0	42.00	19000.00	49600.01	13200.00
12	2	431	910729	0	.0	51	10542	6.80	1.80	130.0	51.00	18000.00	50300.01	12700.00
12	2	431	910729	0	10.5	51	10541	7.10	1.90	110.0	50.00	18000.00	50200.01	12400.00
12	2	436	910729	0	10.0	51	10535	6.50	1.70	100.0	51.00	19000.00	52800.01	12600.00
12	2	436	910729	0	10.0	51	10536	6.60	1.80	110.0	54.00	19000.00	53300.01	12500.00
12	2	437	910729	0	6.0	51	10533	5.30	2.00	97.0	48.00	20000.00	53500.01	13300.00
12	2	437	910729	0	6.0	51	10534	6.80	1.80	99.0	48.00	19000.00	55800.01	12900.00
12	2	441	910730	0	7.2	51	10523	4.50	1.50	88.0	42.00	17000.00	38900.00	11800.00
12	2	441	910730	0	7.2	51	10524	5.10	1.50	97.0	40.00	17000.00	38600.00	11900.00
12	2	443	910729	0	5.6	51	10539	6.60	1.70	110.0	53.00	21000.00	47300.01	13100.00
12	2	443	910729	0	5.6	51	10540	7.70	1.80	110.0	55.00	20000.00	49200.01	12500.00
12	2	444	910729	0	4.8	51	10521	9.60	2.90		61.00	19000.00	60000.01	12200.00
12	2	444	910729	0	4.8	51	10522	7.20	2.50	130.0	57.00	19000.00	52600.01	12500.00
12	2	476	910729	0	8.5	51	10531	6.70	1.70	110.0	49.00	18000.00	49000.01	12700.00
12	2	476	910729	0	8.5	51	10532	7.40	1.60	120.0	53.00	17000.00	50600.01	12500.00
12	2	477	910729	0	5.5	51	10529	8.90	2.30	120.0	53.00	19000.00	52400.01	12300.00
12	2	477	910729	0	5.5	51	10530	7.40	1.90	110.0	54.00	19000.00	51100.01	12300.00
12	2	478	910730	0	8.1	51	10543	7.00	1.90	99.0	49.00	19000.00	52000.01	13200.00
12	2	478	910730	0	8.1	51	10544	6.00	1.70	93.0	48.00	19000.00	52500.01	13000.00
12	2	479	910730	0	3.0	51	10527	6.40	1.90	100.0	48.00	20000.00	46600.01	12600.00
12	2	479	910730	0	7.6	51	10528	6.20	1.80	100.0	48.00	20000.00	47500.01	12900.00
12	15	2	910729	0	4.0	51	10545	7.30	2.70	140.0	58.00	22000.00	11700.00	10100.00
12	15	2	910729	0	4.0	51	10546	7.80	3.00	120.0	64.00	24000.00	11000.00	10400.00
12	15	3	910730	0	5.8	51	10547	6.30	1.80	100.0	50.00	20000.00	42100.01	12400.00
12	15	3	910730	0	5.8	51	10548	5.90	1.60	110.0	49.00	21000.00	43000.01	12700.00
12	15	4	910730	0	0.0	51	10549	8.30	2.30	200.0	88.00	23000.00	8500.00	8400.00
12	15	4	910730	0	0.0	51	10550	8.10	3.10	190.0	88.00	22000.00	10000.00	8500.00

(b) Bottom sediment grab samples

BOW	STN TYPE	STN #	DATE YYMMDD	TIME	SAMPLE DEPTH (m.)	SMP TYPE	FIELD SAMPLE NUMBER	NNTKUR MG/G D as N	RMK	PPUT MG/G D as P	RMK	RSTLOI MG/G D	RMK	TOC MG/G D as C	RMK	ALUT UG/G D as Al	RMK	CAUT UG/G D as Ca	RMK	MGUT UG/G D as Mg	RMK
12	2	381	910720	1150	2.0	55	41089	0.58		0.48				6.50		4900.00		5200.00		3200.00	
12	2	381	910720	1155	2.0	55	41090	0.58		0.66				8.00		4400.00		4400.00		2700.00	
12	2	401	910720	1005	6.0	55	41079	0.50	<	0.72				2.20		4200.00		15000.00		6400.00	
12	2	401	910720	1010	6.0	55	41080	8.80		0.63				3.00		3200.00		10000.00		4700.00	
12	2	402	910720	1240	4.0	55	41095	1.80		0.85				15.00		8600.00		24000.00		10000.00	
12	2	402	910720	1245	4.0	55	41096	1.50		0.82				14.00		8100.00		25000.00		11000.00	
12	2	431	910720	920	12.0	55	41075	1.80		0.97				6.70		11000.00		40000.00		14000.00	
12	2	431	910720	930	12.0	55	41076	0.50	<	0.73				6.20		5800.00		53000.00		14000.00	
12	2	436	910720	1330	4.0	55	41097	2.80		0.88				27.00		13000.00		44000.00		14000.00	
12	2	436	910720	1335	4.0	55	41098	2.80		0.95				25.00		11000.00		42000.00		13000.00	
12	2	437	910720	1300	3.0	55	41093	2.20		1.00				14.00		7300.00		43000.00		13000.00	
12	2	441	910720	1205	6.0	55	41091	0.66		1.00				4.40		30000.00		38000.00		20000.00	
12	2	441	910720	1220	6.0	55	41092	0.62		0.97				2.50		31000.00		23000.00		21000.00	
12	2	443	910720	1410	3.0	55	41101	5.70		1.50				44.00		17000.00		54000.00		13000.00	
12	2	443	910720	1415	3.0	55	41102	4.90		1.10				43.00		18000.00		51000.00		13000.00	
12	2	444	910720	1350	3.0	55	41099	3.60		0.95				30.00		12000.00		41000.00		13000.00	
12	2	444	910720	1400	3.0	55	41100	1.70		0.95				13.00		9000.00		46000.00		15000.00	
12	2	476	910720	950	3.0	55	41077	0.50	<	1.10				24.00		10000.00		36000.00		12000.00	
12	2	476	910720	955	3.0	55	41078	3.60		0.92				25.00		11000.00		35000.00		12000.00	
12	2	477	910720	850	10.5	55	41073	0.50	<	1.20				18.00		8100.00		45000.00		12000.00	
12	2	477	910720	905	10.5	55	41074	2.10		0.87				16.00		6700.00		46000.00		11000.00	
12	2	478	910720	1045	4.0	55	41083	1.70		0.99				12.00		7700.00		35000.00		12000.00	
12	2	478	910720	1050	4.0	55	41084	1.50		0.93				12.00		7700.00		36000.00		13000.00	
12	2	479	910720	1135	3.0	55	41087	2.80		0.88				29.00		13000.00		25000.00		10000.00	
12	2	479	910720	1140	3.0	55	41088	3.50		1.10				32.00		14000.00		22000.00		11000.00	
12	15	2	910720	1025	6.0	55	41081	7.10		2.00				59.00		24000.00		12000.00		11000.00	
12	15	2	910720	1030	6.0	55	41082	4.40		1.90				53.00		23000.00		12000.00		11000.00	
12	15	3	910720	1105	3.5	55	41085	1.20		0.80				13.00		8200.00		5600.00		3900.00	
12	15	3	910720	1110	3.5	55	41086	1.20		0.69				12.00		8000.00		5000.00		3600.00	

TABLE D.2

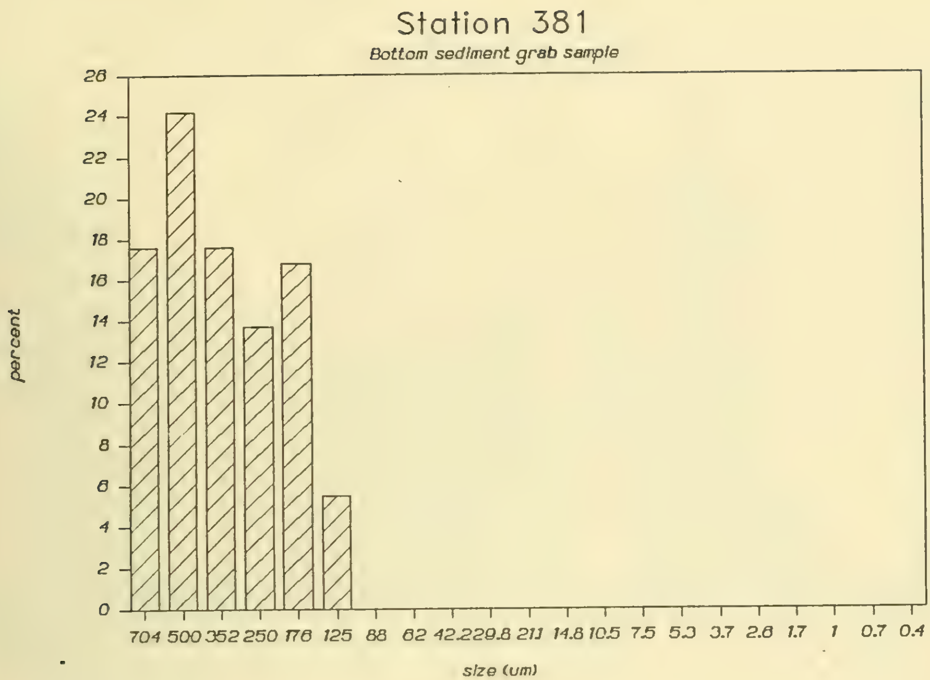
HEAVY METAL CONCENTRATIONS IN SEDIMENTS
CORNWALL LOW-LEVEL METALS SURVEY, JULY 1991

(a) Sediment trap samples

STN #	DATE YYMMDD	FIELD SAMPLE NUMBER	ASUT UG/G D as As	RMK	CDUT UG/G D as Cd	RMK	CRUT UG/G D as Cr	RMK	CUUT UG/G D as Cu	RMK	FEUT UG/G D as Fe	RMK	HGUT UG/G D as Hg	RMK	MNUT UG/G D as Mn	RMK	NIUT UG/G D as Ni	RMK	PBUT UG/G D as Pb	RMK	ZNUT UG/G D as Zn	RMK
401	910729	10537	5.30		1.30		33.00		30.00		20000.00		0.11		530.000		26.00		24.00		110.00	
401	910729	10538	4.80		1.40		31.00		30.00		19000.00		0.09		480.000		25.00		19.00		110.00	
402	910730	10525	4.00		1.60		39.00		38.00		23000.00		0.11		670.000		32.00		30.00		130.00	
402	910730	10526	5.50		1.70		40.00		50.00		23000.00		0.12		740.000		31.00		32.00		140.00	
431	910729	10542	6.30		1.70		41.00		91.00		22000.00		0.49		540.000		32.00		36.00		430.00	
431	910729	10541	6.80		1.70		39.00		83.00		21000.00		0.51		570.000		31.00		38.00		430.00	
436	910729	10535	5.80		1.70		43.00		50.00		22000.00		0.23		480.000		30.00		29.00		270.00	
436	910729	10536	5.70		1.60		41.00		82.00		22000.00		0.26		500.000		32.00		40.00		300.00	
437	910729	10533	5.70		1.80		42.00		49.00		24000.00		0.14		720.000		32.00		27.00		140.00	
437	910729	10534	5.10		1.70		42.00		66.00		23000.00		0.17		650.000		31.00		28.00		150.00	
441	910730	10523	4.80		1.40		35.00		32.00		22000.00		0.12		670.000		28.00		26.00		140.00	
441	910730	10524	3.30		1.40		35.00		32.00		22000.00		0.12		680.000		28.00		27.00		140.00	
443	910729	10539	7.10		1.90		47.00		51.00		24000.00		0.52		660.000		34.00		39.00		490.00	
443	910729	10540	6.80		1.80		45.00		49.00		23000.00		0.54		440.000		34.00		36.00		500.00	
444	910729	10521	4.30		1.80		40.00		66.00		23000.00		0.15		650.000		33.00		33.00		160.00	
444	910729	10522	5.00		1.80		41.00		59.00		23000.00		0.18		840.000		33.00		32.00		160.00	
476	910729	10531	5.20		1.60		39.00		47.00		21000.00		0.28		440.000		29.00		32.00		130.00	
476	910729	10532	5.80		1.50		37.00		46.00		20000.00		0.47		470.000		28.00		26.00		130.00	
477	910729	10529	6.00		1.50		42.00		49.00		22000.00		0.37		540.000		30.00		31.00		310.00	
477	910729	10530	6.30		1.50		43.00		48.00		22000.00		0.35		430.000		30.00		32.00		320.00	
478	910730	10543	5.20		1.70		41.00		43.00		23000.00		0.13		590.000		32.00		28.00		140.00	
478	910730	10544	5.60		1.80		40.00		44.00		23000.00		0.11		650.000		32.00		28.00		140.00	
479	910730	10527	5.00		1.90		40.00		46.00		24000.00		0.14		670.000		32.00		27.00		160.00	
479	910730	10528	5.10		1.70		42.00		44.00		25000.00		0.13		760.000		32.00		28.00		160.00	
2	910729	10545	7.80		1.50		50.00		48.00		35000.00		0.25		2300.000		32.00		29.00		180.00	
2	910729	10546	8.20		1.80		60.00		53.00		37000.00		0.23		2800.000		38.00		39.00		200.00	
3	910730	10547	5.10		1.80		43.00		38.00		25000.00		0.14		740.000		33.00		34.00		160.00	
3	910730	10548	5.20		1.90		45.00		39.00		26000.00		0.13		770.000		33.00		32.00		170.00	
4	910730	10549	7.20		2.30		55.00		22.00		40000.00		0.15		3600.000		27.00		38.00		230.00	
4	910730	10550	7.00		1.80		56.00		22.00		39000.00		0.16		4100.000		25.00		34.00		230.00	

(b) Bottom sediment grab samples

STN #	DATE YYMMDD	FIELD SAMPLE NUMBER	ASUT UG/G D as As	RMK	CDUT UG/G D as Cd	RMK	CRUT UG/G D as Cr	RMK	CUUT UG/G D as Cu	RMK	FEUT UG/G D as Fe	RMK	HGUT UG/G D as Hg	RMK	MNUT UG/G D as Mn	RMK	NIUT UG/G D as Ni	RMK	PBUT UG/G D as Pb	RMK	ZNUT UG/G D as Zn	RMK
381	910720	41089	0.89	<T	0.05	<W	12.00		3.40		14000.00		0.01	<W	180.000		4.80		1.80	<T	50.00	
381	910720	41090	0.98	<T	0.05	<W	11.00		2.40	<T	15000.00		0.01	<W	200.000		4.70		3.40	<T	51.00	
401	910720	41079	1.10		0.05	<W	12.00		5.20		9800.00		0.01	<W	160.000		7.50		3.80	<T	27.00	
401	910720	41080	1.10		0.05	<W	8.50		4.00		7100.00		0.01	<W	120.000		5.30		4.90	<T	21.00	
402	910720	41095	1.80		0.21	<T	19.00		13.00		13000.00		0.05	<T	190.000		12.00		11.00		72.00	
402	910720	41096	1.90		0.45		17.00		13.00		12000.00		0.01	<W	270.000		11.00		11.00		72.00	
431	910720	41075	1.80		0.05	<W	26.00		17.00		21000.00		0.05	<T	330.000		16.00		9.60		79.00	
431	910720	41076	1.30		0.06	<T	19.00		14.00		18000.00		0.02	<T	260.000		11.00		8.70		71.00	
436	910720	41097	3.70		0.65		31.00		31.00		16000.00		0.32		270.000		21.00		32.00		150.00	
436	910720	41098	3.10		0.71		27.00		27.00		15000.00		0.29		260.000		18.00		22.00		130.00	
437	910720	41093	1.20		0.29		18.00		15.00		14000.00		0.01	<W	260.000		13.00		9.20		51.00	
441	910720	41091	4.80		0.43		55.00		33.00		36000.00		0.01	<W	790.000		35.00		12.00		110.00	
441	910720	41092	5.00		0.07	<T	58.00		37.00		39000.00		0.02	<T	730.000		37.00		8.70		110.00	
443	910720	41101	5.60		1.10		40.00		43.00		20000.00		0.53		350.000		26.00		38.00		460.00	
443	910720	41102	5.30		1.10		41.00		44.00		20000.00		0.51		350.000		27.00		37.00		470.00	
444	910720	41099	3.20		0.72		26.00		25.00		16000.00		0.05	<T	280.000		20.00		19.00		94.00	
444	910720	41100	2.20		0.45		21.00		18.00		14000.00		0.03	<T	250.000		15.00		11.00		64.00	
476	910720	41077	2.60		0.07	<T	25.00		33.00		14000.00		0.43		240.000		17.00		27.00		83.00	
476	910720	41078	2.70		0.31		25.00		28.00		15000.00		0.44		230.000		17.00		21.00		79.00	
477	910720	41073	2.90		0.09	<T	20.00		27.00		14000.00		0.16		290.000		14.00		14.00		150.00	
477	910720	41074	1.70		0.25	<T	18.00		16.00		12000.00		0.29		230.000		12.00		15.00		120.00	
478	910720	41083	2.00		0.63		19.00		14.00		13000.00		0.05	<T	270.000		12.00		14.00		59.00	
478	910720	41084	2.00		0.33		20.00		16.00		13000.00		0.02	<T	270.000		12.00		13.00		58.00	
479	910720	41087	3.10		0.79		28.00		23.00		18000.00		0.07		300.000		17.00		18.00		110.00	
479	910720	41088	3.00		0.60		28.00		23.00		19000.00		0.09		350.000		18.00		21.00		120.00	
2	910720	41081	4.00		1.40		45.00		69.00		32000.00		0.17		790.000		27.00		42.00		250.00	
2	910720	41082	4.20		1.30		45.00		68.00		30000.00		0.15		710.000		28.00		41.00		240.00	
3	910720	41085	1.30		0.31		17.00		12.00		15000.00		0.05	<T	250.000		6.50		14.00		110.00	
3	910720	41086	1.20		0.18	<T	15.00		8.00		12000.00		0.05	<T	230.000		6.30		12.00		110.00	


Station 381
Bottom sediment grab sample
percent
0
2
4
6
8
10
12
14
16
18
20
22
24
26
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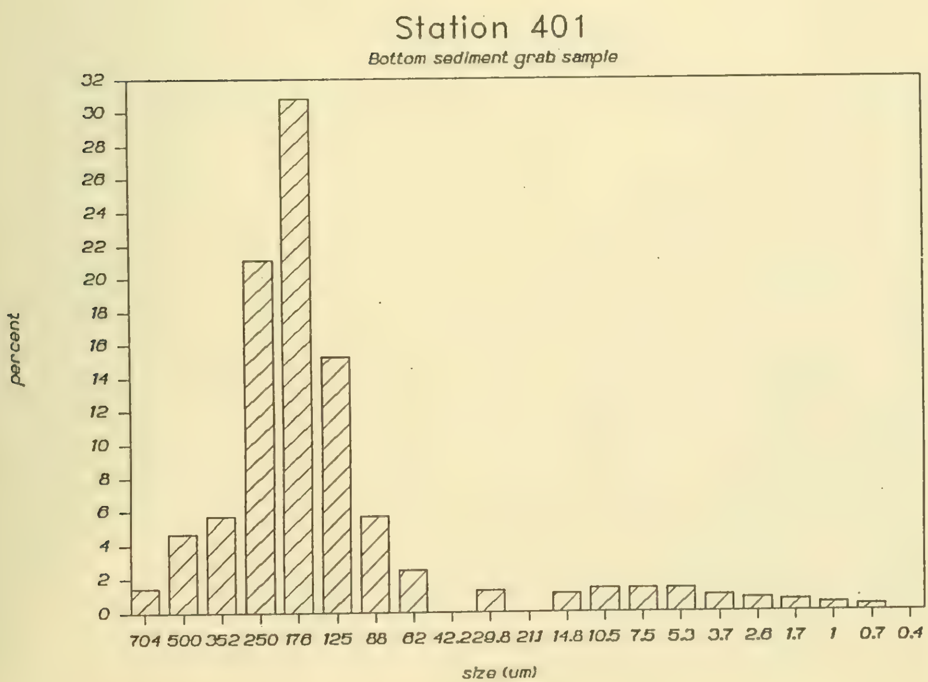
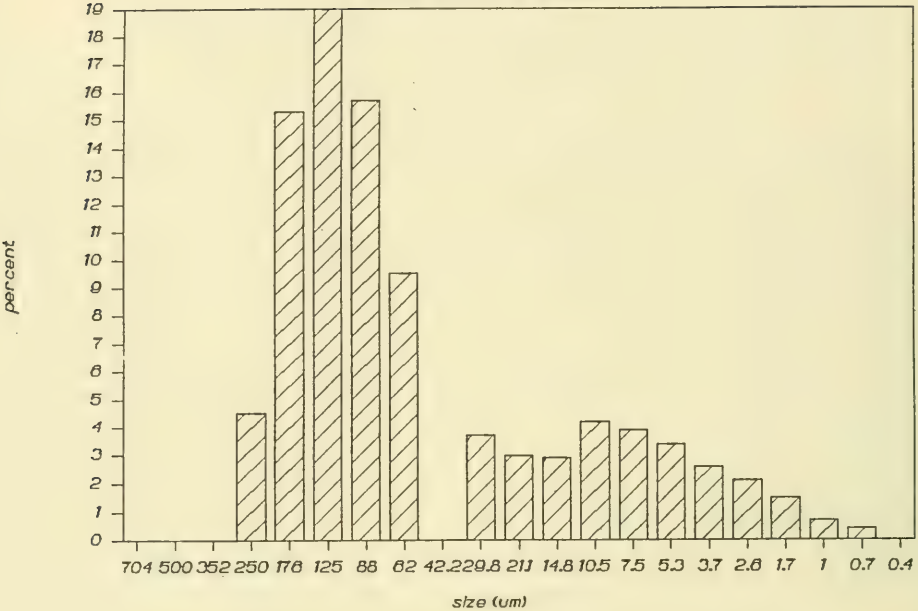
size (um)


Station 401
Bottom sediment grab sample
percent
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
704 500 352 250 176 125 88 62 42.2 29.8 21.1 14.8 10.5 7.5 5.3 3.7 2.6 1.7 1 0.7 0.4
size (um)

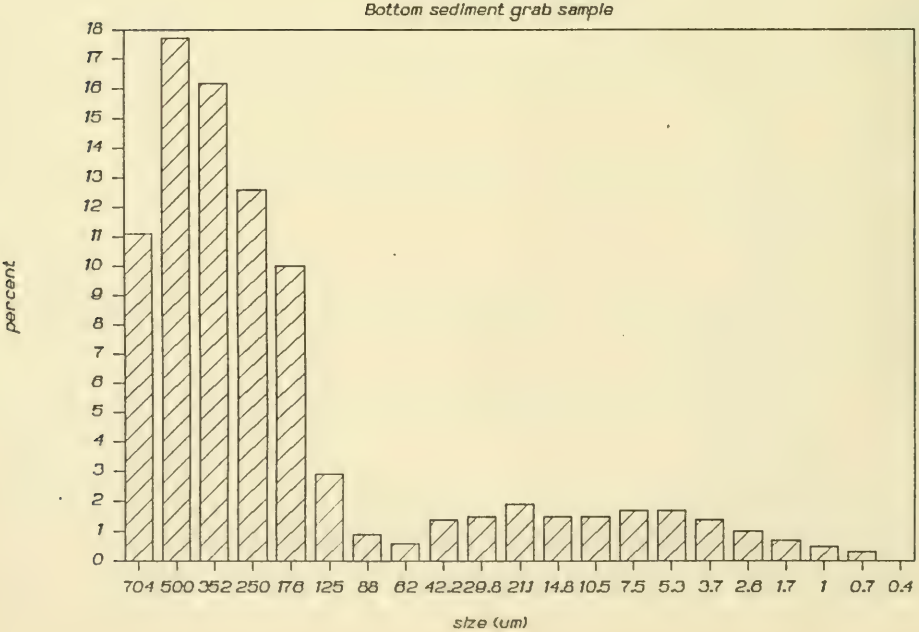
Station 402

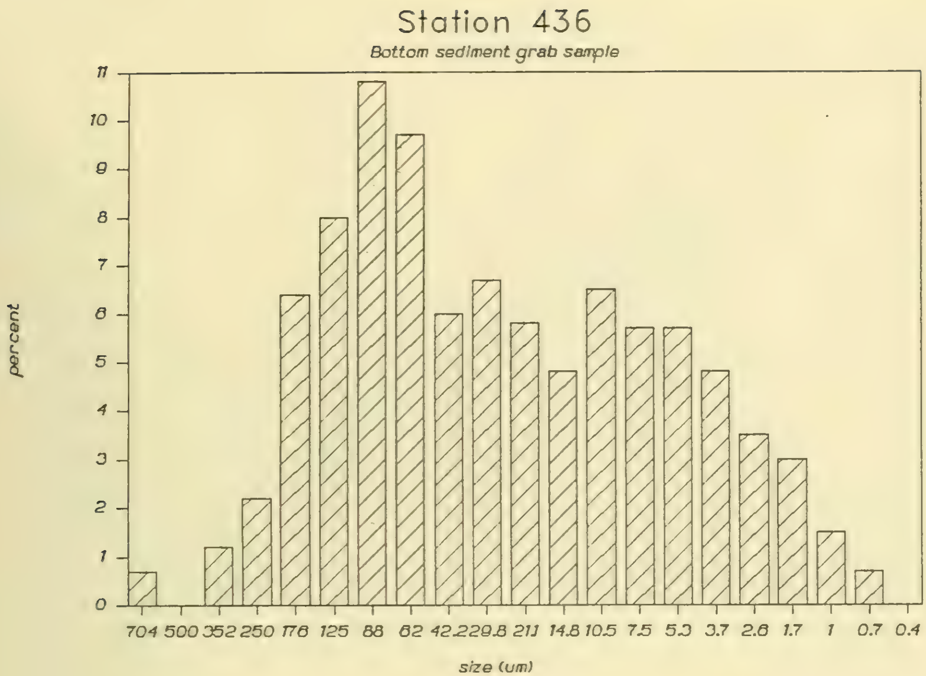
Bottom sediment grab sample



Station 431

Bottom sediment grab sample




Station 436
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
10
11
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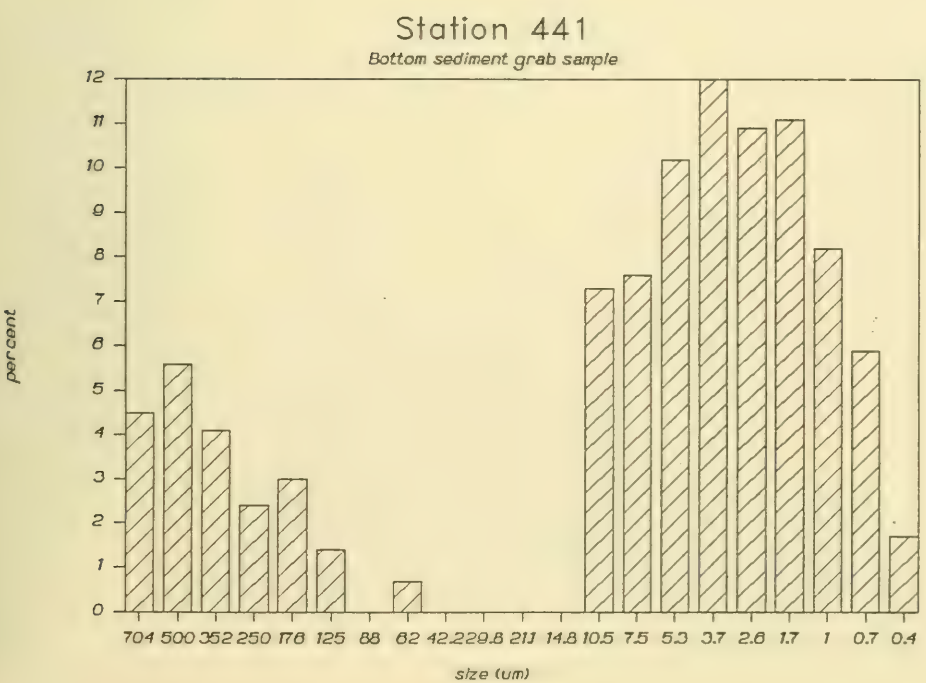
size (um)


Station 441
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
10
11
12
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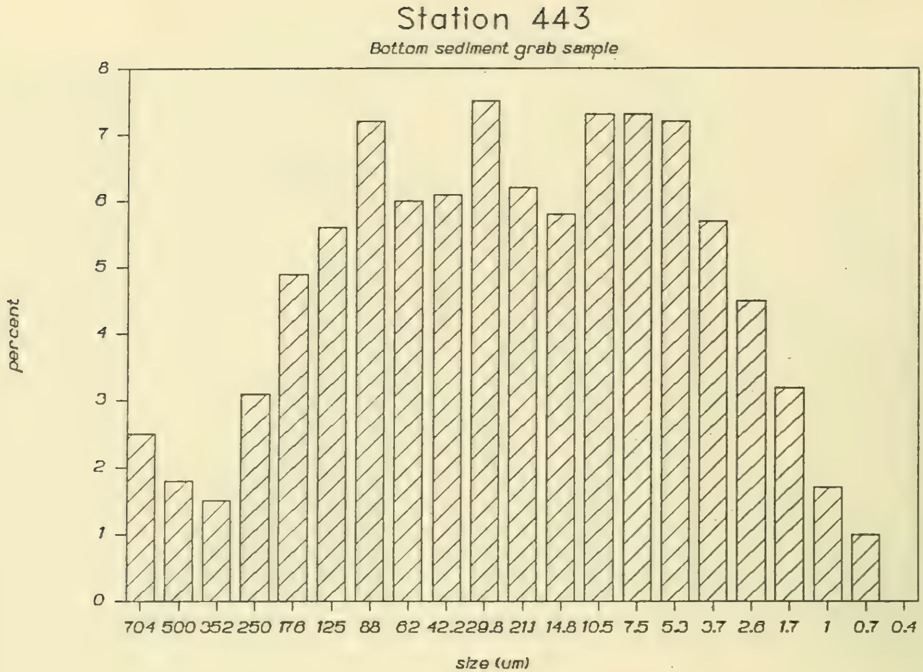
size (um)


Station 443
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
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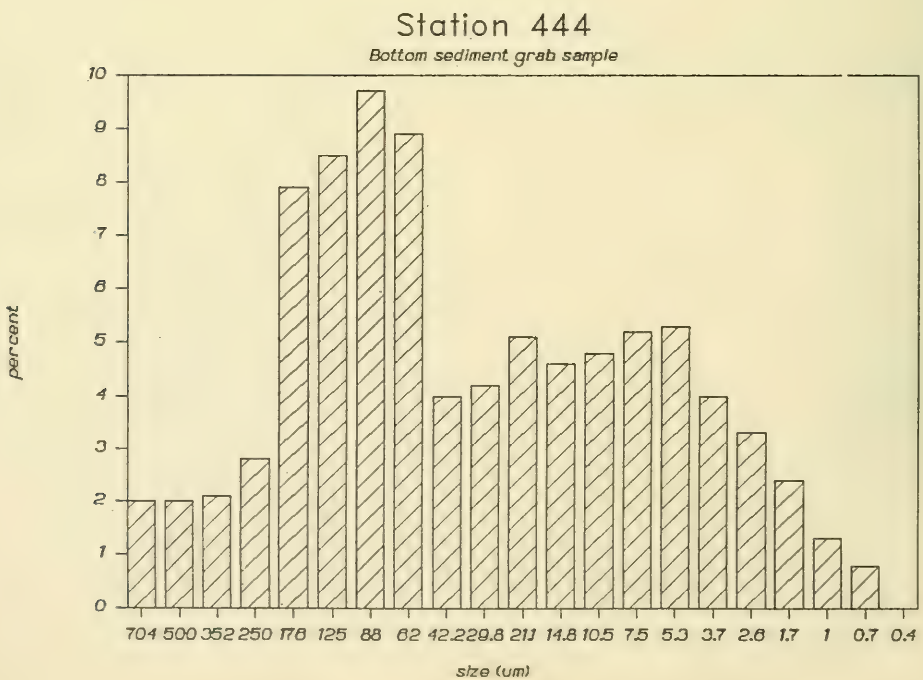
size (um)


Station 444
Bottom sediment grab sample
percent
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1
2
3
4
5
6
7
8
9
10
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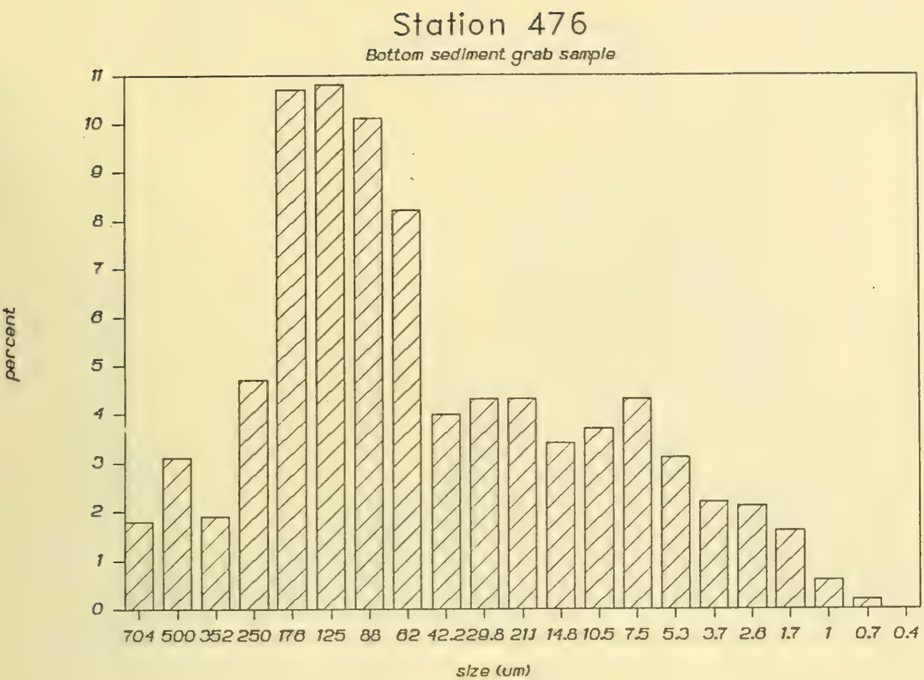
size (um)



Station 476
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
10
11
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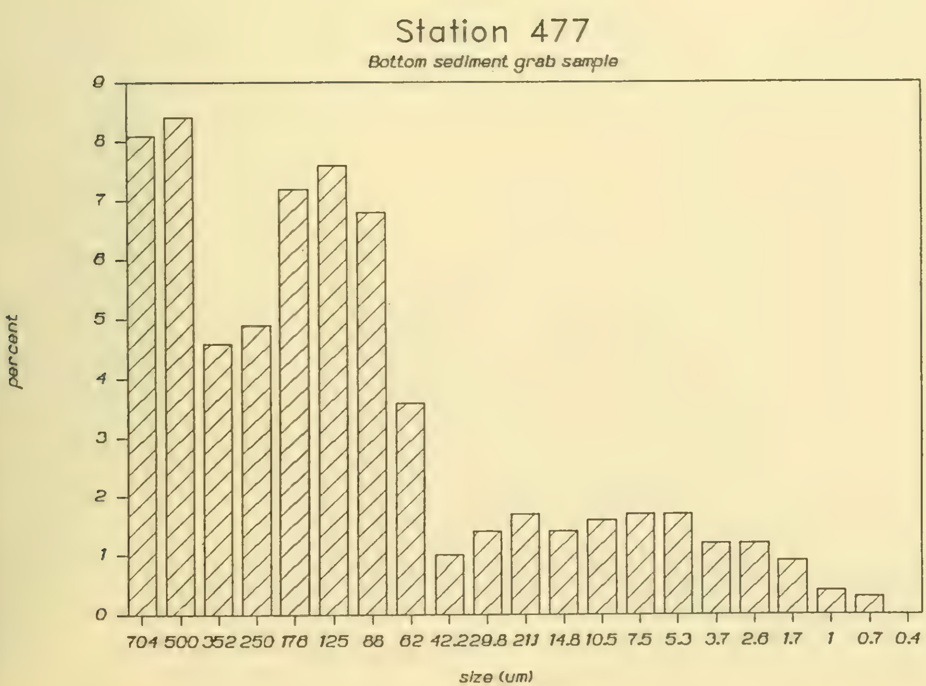
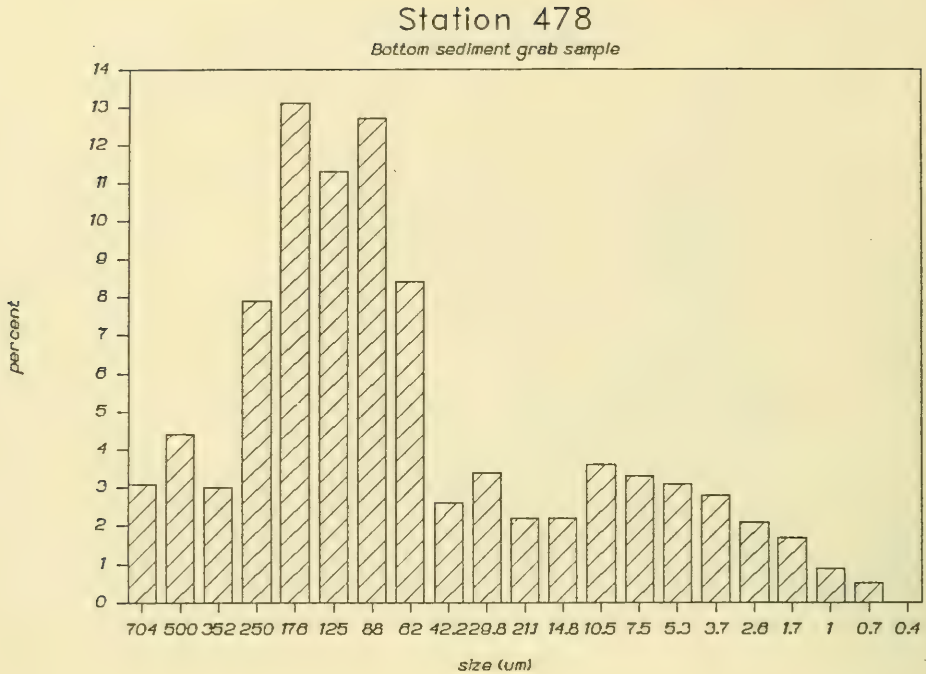
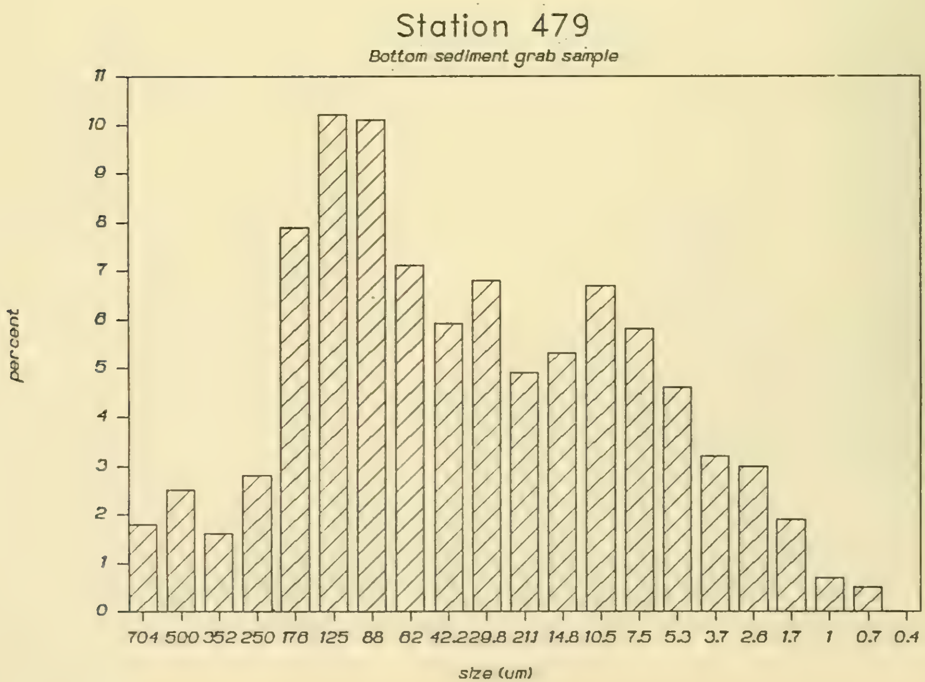
size (um)



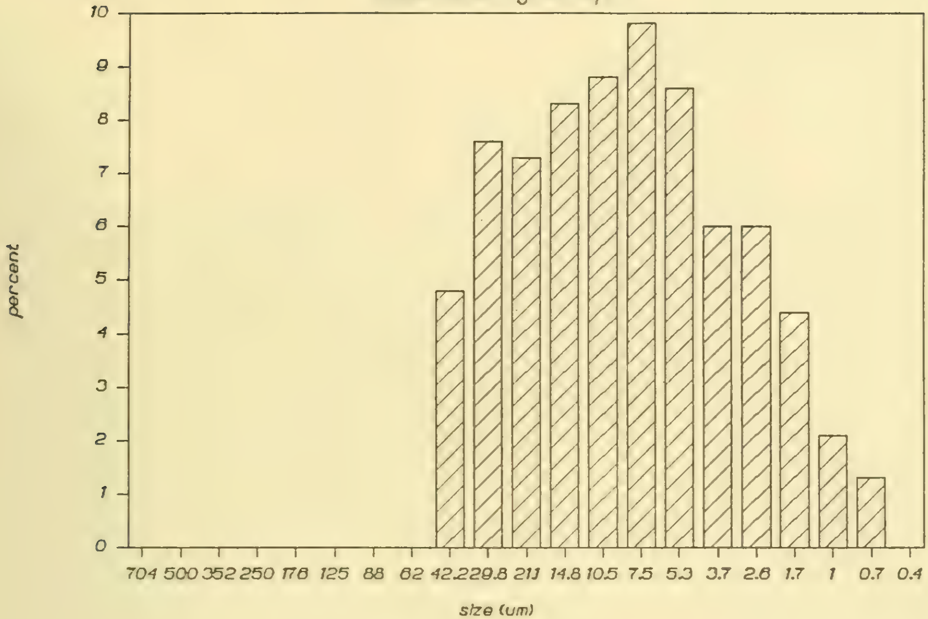
Station 477
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
704 500 352 250 176 125 88 62 42.2 29.8 21.1 14.8 10.5 7.5 5.3 3.7 2.6 1.7 1 0.7 0.4
size (um)


Station 478
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
704 500 352 250 176 125 88 62 42.2 29.8 21.1 14.8 10.5 7.5 5.3 3.7 2.6 1.7 1 0.7 0.4
size (um)


Station 479
Bottom sediment grab sample
percent
0
1
2
3
4
5
6
7
8
9
10
11
704 500 352 250 176 125 88 62 42.2 29.8 21.1 14.8 10.5 7.5 5.3 3.7 2.6 1.7 1 0.7 0.4
size (um)

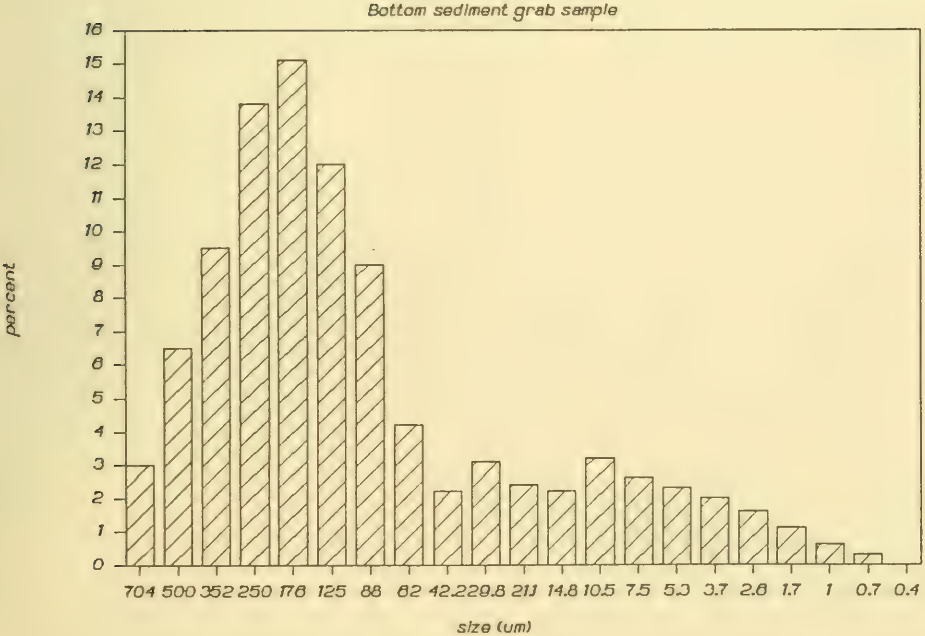
Station 15-02

Bottom sediment grab sample



Station 15-03

Bottom sediment grab sample



APPENDIX E

Particulate metal levels in St. Lawrence River

PARTICULATE METAL LEVELS IN ST. LAWRENCE RIVER
AS OBTAINED FROM SEDIMENT TRAP DATA

		ASUT	CDUT	CRUT	CUUT	FEUT	HGUT	MNUT	NIUT	PBUT	ZNUT
		UG/L	UG/L	UG/L	UG/L	UG/L	NG/L	UG/L	UG/L	UG/L	UG/L
stat = 401	mean =	.0160	.0043	.1016	.0953	61.9125	.3175	1.6034	.0810	.0683	.3492
	sd =	.0021	.0005	.0127	.0114	7.6192	.0512	.2104	.0099	.0118	.0419
	min =	.0130	.0035	.0837	.0810	51.3000	.2430	1.2960	.0675	.0513	.2970
	max =	.0196	.0052	.1221	.1110	74.0000	.4070	1.9610	.0962	.0888	.4070
stat = 402	mean =	.0128	.0045	.1067	.1188	62.1000	.3105	1.9035	.0851	.0837	.3645
	sd =	.0025	.0005	.0109	.0211	6.2687	.0345	.2173	.0087	.0089	.0395
	min =	.0096	.0038	.0936	.0912	55.2000	.2640	1.6080	.0744	.0720	.3120
	max =	.0165	.0051	.1200	.1500	69.0000	.3600	2.2200	.0960	.0960	.4200
stat = 431	mean =	.0293	.0076	.1790	.3893	96.2125	2.2375	2.4836	.1410	.1656	1.9243
	sd =	.0070	.0018	.0423	.0935	22.7329	.5279	.5880	.0332	.0392	.4520
	min =	.0214	.0058	.1326	.2822	71.4000	1.6660	1.8360	.1054	.1224	1.4620
	max =	.0381	.0095	.2296	.5096	123.2000	2.8560	3.1920	.1792	.2128	2.4080
stat = 436	mean =	.0187	.0054	.1365	.2145	71.5000	.7962	1.5925	.1007	.1121	.9263
	sd =	.0010	.0003	.0082	.0569	3.9002	.0679	.0936	.0065	.0201	.0726
	min =	.0171	.0048	.1230	.1500	66.0000	.6900	1.4400	.0900	.0870	.8100
	max =	.0197	.0058	.1462	.2788	74.8000	.8840	1.7000	.1088	.1360	1.0200
stat = 437	mean =	.0173	.0056	.1344	.1840	75.2000	.4960	2.1920	.1008	.0880	.4640
	sd =	.0033	.0010	.0246	.0448	13.8691	.1046	.4191	.0185	.0162	.0867
	min =	.0133	.0044	.1092	.1274	59.8000	.3640	1.6900	.0806	.0702	.3640
	max =	.0228	.0072	.1680	.2640	96.0000	.6800	2.8800	.1280	.1120	.6000
stat = 441	mean =	.0099	.0034	.0857	.0784	53.9000	.2940	1.6537	.0686	.0649	.3430
	sd =	.0023	.0004	.0101	.0092	6.3326	.0345	.1947	.0081	.0077	.0403
	min =	.0069	.0029	.0735	.0672	46.2000	.2520	1.4070	.0588	.0546	.2940
	max =	.0134	.0039	.0980	.0896	61.6000	.3360	1.9040	.0784	.0756	.3920
stat = 443	mean =	.0221	.0059	.1461	.1587	74.6125	1.6827	1.7462	.1079	.1191	1.5716
	sd =	.0024	.0006	.0157	.0170	8.0031	.1796	.4174	.0113	.0135	.1656
	min =	.0184	.0049	.1215	.1323	62.1000	1.4040	1.1880	.0918	.0972	1.3230
	max =	.0248	.0066	.1645	.1785	84.0000	1.8900	2.3100	.1190	.1365	1.7500
stat = 444	mean =	.0127	.0049	.1104	.1703	62.6750	.4496	2.0301	.0899	.0886	.4360
	sd =	.0010	.0001	.0024	.0106	1.0646	.0444	.2789	.0015	.0021	.0074
	min =	.0116	.0049	.1080	.1593	62.1000	.4050	1.7550	.0891	.0864	.4320
	max =	.0140	.0050	.1148	.1848	64.4000	.5040	2.3520	.0924	.0924	.4480

		ASUT UG/L	CDUT UG/L	CRUT UG/L	CUUT UG/L	FEUT UG/L	HGUT NG/L	MNUT UG/L	NIUT UG/L	PBUT UG/L	ZNUT UG/L
stat = 476	mean =	.0209	.0059	.1444	.1767	77.9000	1.4250	1.7290	.1083	.1102	.4940
	sd =	.0017	.0004	.0095	.0107	5.0745	.3958	.1199	.0068	.0139	.0295
	min =	.0182	.0052	.1295	.1610	70.0000	.9800	1.5400	.0980	.0910	.4550
	max =	.0232	.0064	.1560	.1880	84.0000	1.8800	1.8800	.1160	.1280	.5200
stat = 477	mean =	.0226	.0055	.1562	.1782	80.8500	1.3230	1.7824	.1102	.1158	1.1576
	sd =	.0025	.0006	.0169	.0193	8.7011	.1478	.2898	.0119	.0126	.1261
	min =	.0186	.0047	.1302	.1488	68.2000	1.0850	1.3330	.0930	.0961	.9610
	max =	.0252	.0060	.1720	.1960	88.0000	1.4800	2.1600	.1200	.1280	1.2800
stat = 478	mean =	.0132	.0043	.0992	.1066	56.3500	.2940	1.5190	.0784	.0686	.3430
	sd =	.0023	.0007	.0170	.0182	9.6019	.0567	.2708	.0134	.0117	.0584
	min =	.0099	.0032	.0760	.0817	43.7000	.2090	1.1210	.0608	.0532	.2660
	max =	.0168	.0054	.1230	.1320	69.0000	.3900	1.9500	.0960	.0840	.4200
stat = 479	mean =	.0135	.0048	.1097	.1204	65.5375	.3611	1.9126	.0856	.0736	.4280
	sd =	.0010	.0005	.0089	.0097	5.2299	.0312	.1954	.0066	.0058	.0328
	min =	.0120	.0041	.0960	.1056	57.6000	.3120	1.6080	.0768	.0648	.3840
	max =	.0148	.0055	.1218	.1334	72.5000	.4060	2.2040	.0928	.0812	.4640
stat =15-02	mean =	.0232	.0048	.1595	.1464	104.4000	.6960	7.3950	.1015	.0986	.5510
	sd =	.0015	.0005	.0181	.0115	6.8314	.0511	.8879	.0110	.0166	.0447
	min =	.0211	.0041	.1350	.1296	94.5000	.6210	6.2100	.0864	.0783	.4860
	max =	.0254	.0056	.1860	.1643	114.7000	.7750	8.6800	.1178	.1209	.6200
stat =15-03	mean =	.0174	.0062	.1485	.1299	86.0625	.4556	2.5481	.1114	.1114	.5569
	sd =	.0051	.0019	.0440	.0384	25.4502	.1357	.7536	.0328	.0331	.1653
	min =	.0117	.0041	.0989	.0874	57.5000	.2990	1.7020	.0759	.0736	.3680
	max =	.0224	.0082	.1935	.1677	111.8000	.6020	3.3110	.1419	.1462	.7310